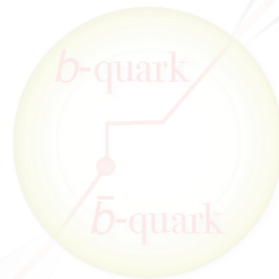


A diagram illustrating the concept of a b-tagged jet. It shows a primary vertex (QGP at Primary Vertex) and a secondary vertex. A b-quark and an anti-b-quark are shown originating from the primary vertex. The b-quark decays into a b-jet and a lepton or hadron (l or h). The anti-b-quark decays into a b-jet and a hadron (h). The distance of closest approach is indicated between the primary and secondary vertices. The text "b-tagged jet" is prominently displayed in the center.

b -tagged jet

Requirement and Performance Update

QGP at
Primary
Vertex

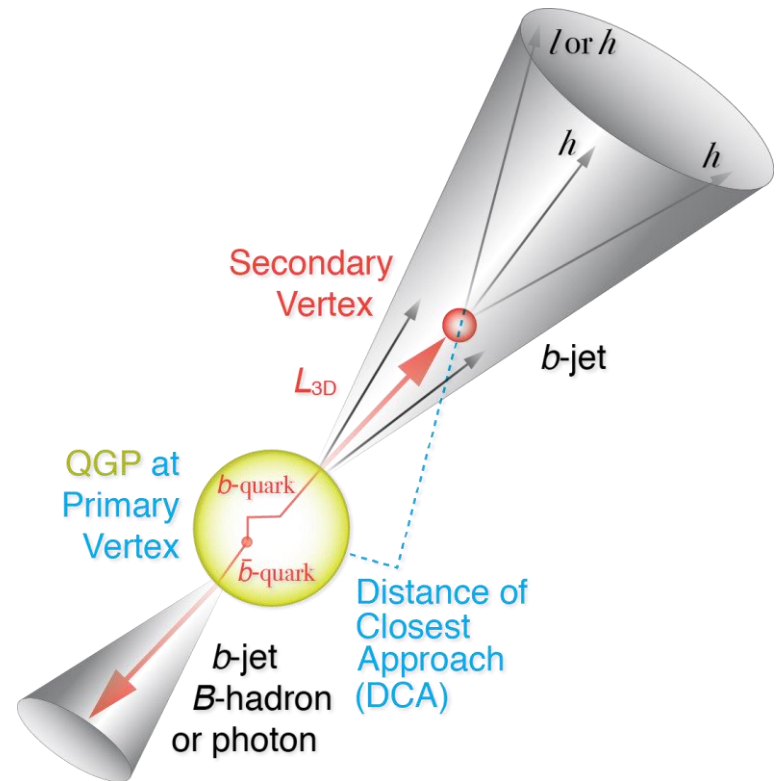
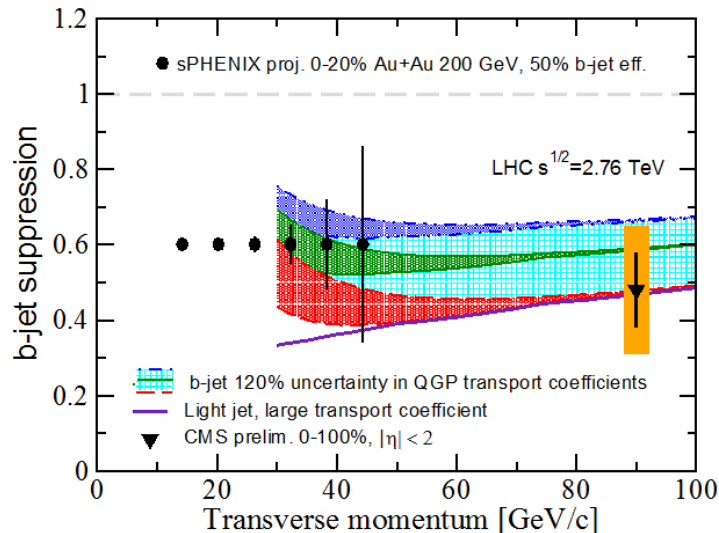


Jin Huang (BNL)

Mike McCumber (LANL)

Distance of
Closest
Approach

Introduction



- ▶ **HF-jet**: in particular *b*-jet, when compared with much more abundant light-parton jet, provide differentiating sensitivity to collision VS radiative energy loss
- ▶ **Complimentary** to current and future RHIC **HF-hadron/lepton** measurements (see also talk of Ming/Xin): “no” FF complication, probing parton energy and higher-scale
- ▶ **Detection technique** employed: Jet + jet structure information enhancing *B*-hadron fraction, i.e: displaced track, high mass secondary vertex and enhanced leptonic decay products
- ▶ **HF-jet topical group** formed in Apr 2016 and initiated Geant4 based *b*-jet study in sPHENIX. Many progresses in simulation tool, *b*-jet tagger and studying new observables.
- ▶ This talk will focus on updates for MAPS/MVTX proposal: 1. detector requirement; 2. first HIJING embedding *b*-jet simulations (Haiwang, Sanghoon); 3. *b*-jet correlation studies (Darren, Xuan)

Topical group organization

▶ Co-conveners

- Jin Huang (Brookhaven National Lab)
<jhuang@bnl.gov>
- Mike McCumber (Los Alamos National Lab)
<mccumber@bnl.gov>



▶ We are very fortunate to have a diligent team working on a wide spectrum of high-priority development

- More manpower are always welcomed and needed!

▶ Communication:

- Discussion email list:
<https://lists.bnl.gov/mailman/listinfo/sphenix-hf-jets-l>
- Wiki page under construction:
https://wiki.bnl.gov/SPHENIX/index.php/Heavy_Flavor_Topical_Group

▶ Meetings/Events

- Use weekly simulation meetings for updates, as many high-priority tasks involve software developments with tracking detector designs
<https://indico.bnl.gov/categoryDisplay.py?categId=88>
- Goal oriented irregular events:
 - New event: this workfest today
 - MAPS+HF-jet workfest, Jan 5-7 2017 @ Santa Fe
 - First work-fest on May 16-17
 - Initial TG meeting on Apr 22

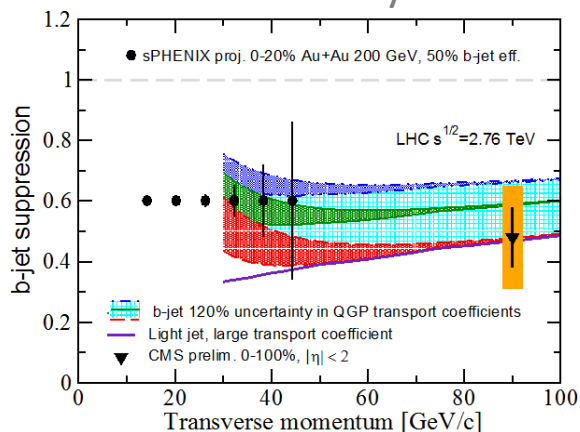


Summary on HF-jet topical group's High priority development tasks

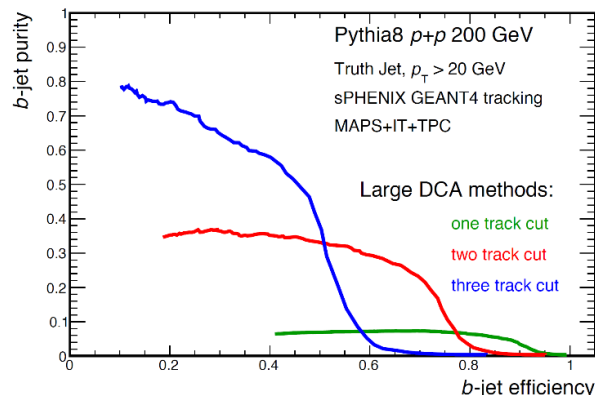
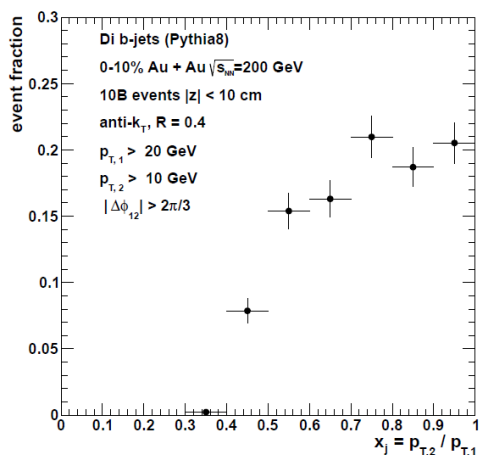
- ▶ Realistic implementation in Geant4
 - Made major progress by Tony and Haiwang
 - Near term goal – understand INTT thickness and merge for general user – Tony, Gaku, Haiwang
- ▶ Pile up simulation
 - Mike McCumber developed framework and init tests.
 - Near term goal – complete development for general user – Mike + Gaku
- ▶ Generalized Kalman filter
 - Haiwang Y./Chris P., Improved with ladder geometry
- ▶ Multi-vertexing/ b -tagging via secondary vertexing in jet
 - Sanghoon L./Haiwang Y.: improve fitting utility,
 - Near term goal - HI analysis – Sanghoon
- ▶ b -jet tagging: Track Counting
 - Haiwang Y./Dennis P.: produced first HIJING performance plot with 7-layer MAPS VS Silicon
 - Near term goal – Certify MAPS+IT+TPC plot for HIJING embedding performance – Haiwang
- ▶ b -jet tagging: Soft Lepton Tagging, exploratory
- ▶ b -quark jet selection: di-bjet asymmetry
 - Darren volunteered to lead the work
 - Near term goal – di-jet imbalance projection plot for proposal and QM17 – Darren
- ▶ b -quark jet selection: Also Xuan Li (LANL) started look at B-meson- b -jet correlations

Plots for MAPS pre-proposal and QM17

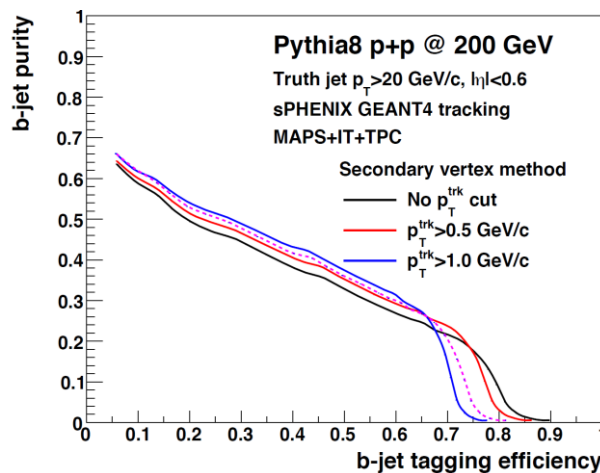
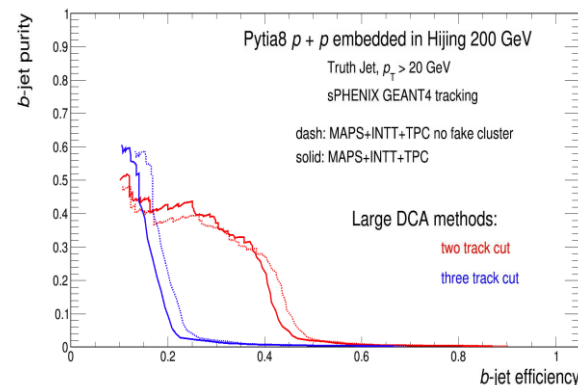
Need to update to the final
int. lumi. + theory curves



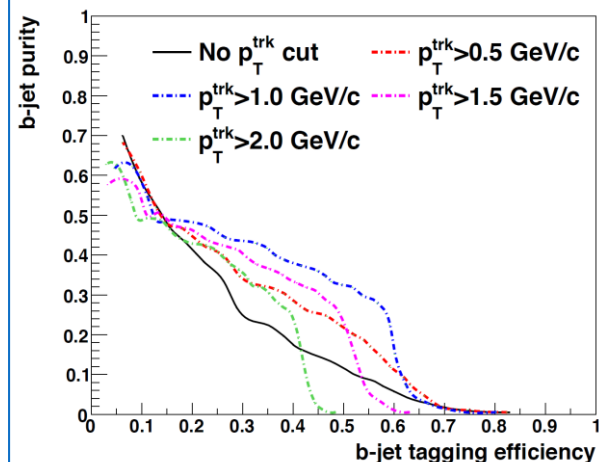
New: di-*b*-jet asymmetry



Still preliminary: HIJING-embedded



Place holder for HIJING-embedded



Observable Projections

b-jet tagger/track counting

b-jet tagger/2nd-vertex



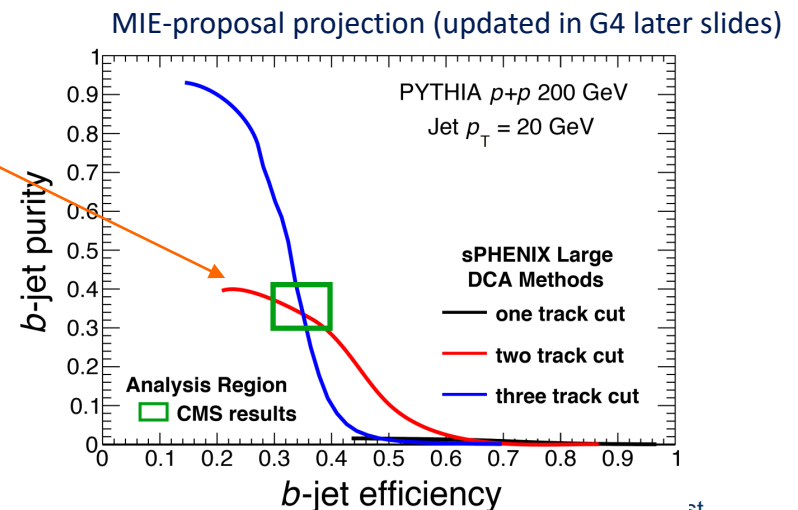
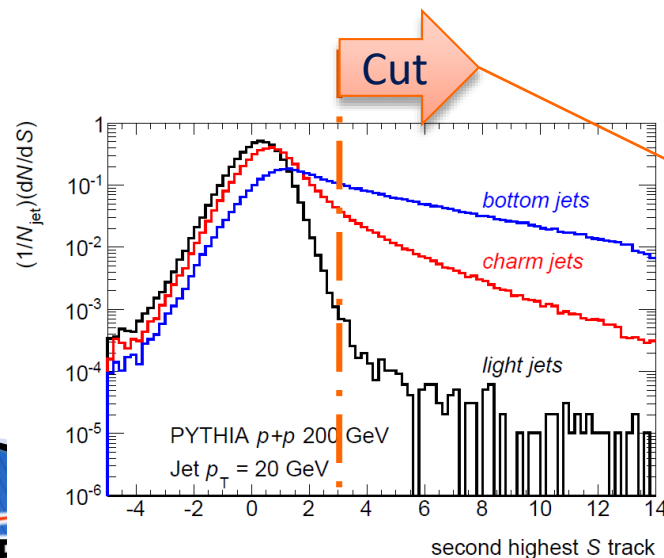
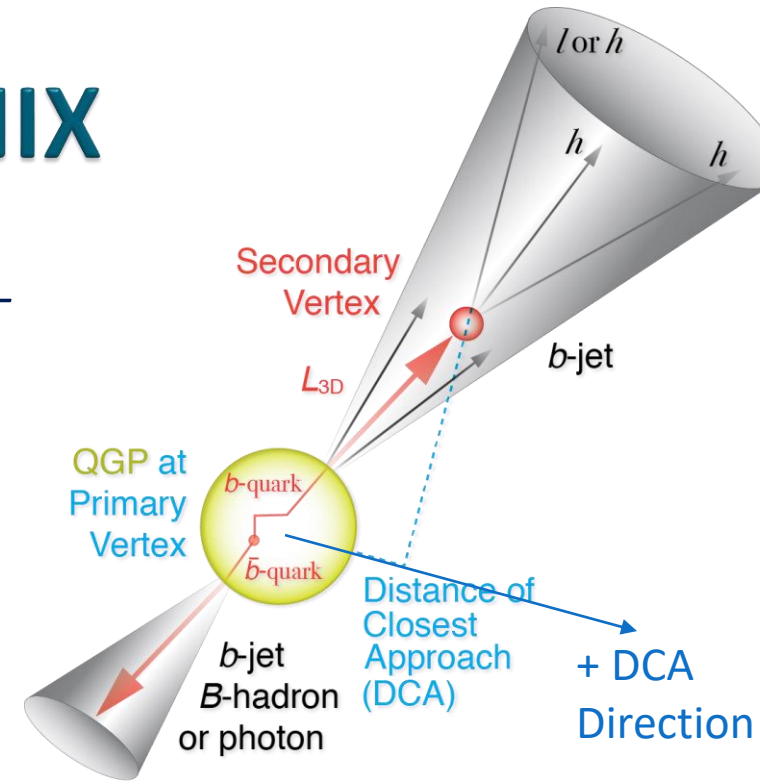
Detector requirement



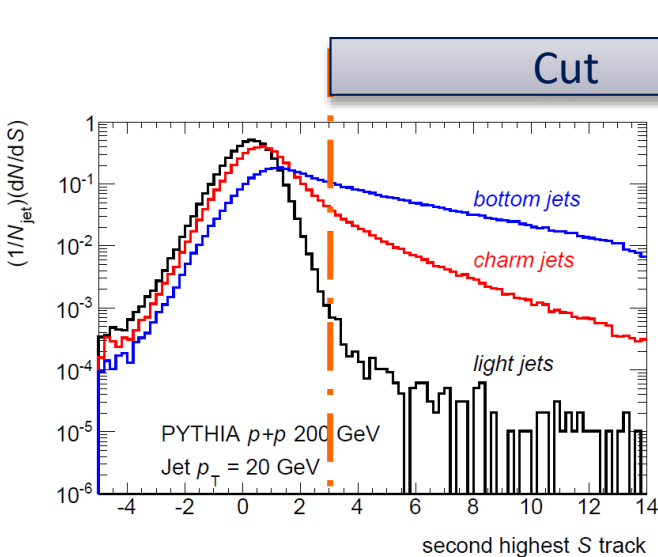
Tagging b -jets in sPHENIX

Exploring three leading methods for sPHENIX b -jets identification and crosscheck

- ▶ Multiple large DCA tracks
- ▶ Secondary vertex and kinematic fits
- ▶ B -meson tagging via semi-leptonic decay or direct invariant mass reconstruction
 - Need volunteer



What affects performance curves

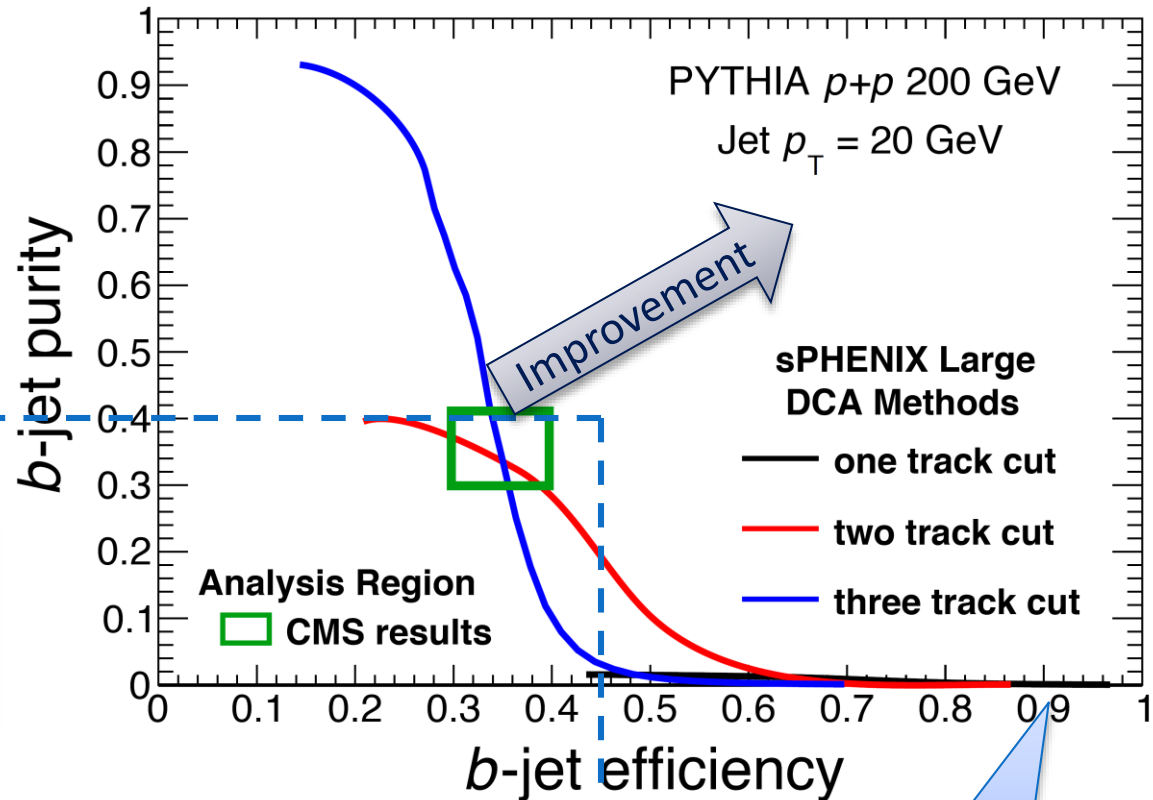


Saturate efficiency at level determined by

- Control light decay-background
- Fake high DCA (mismatching, alignment) → realistic sim.

Performance turn-on at primary particle's DCA peak
 Efficiency improve w/ higher DCA precision and tracking eff.

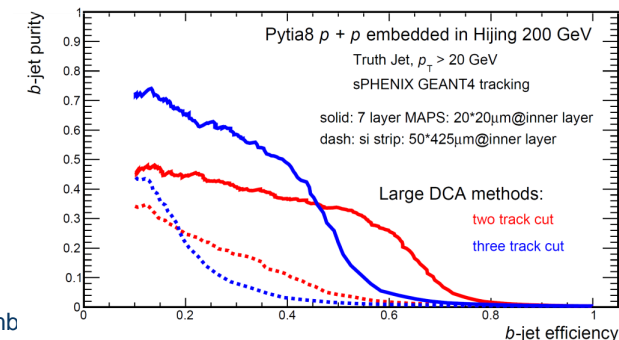
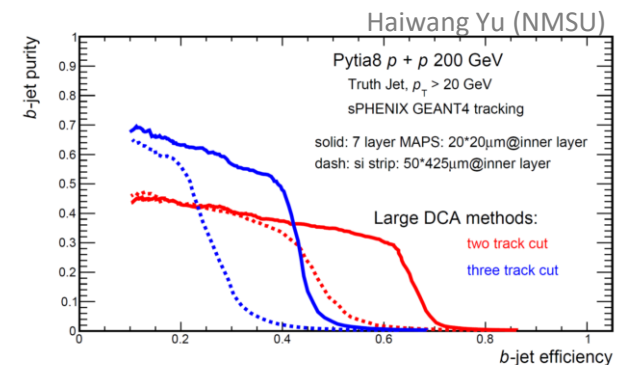
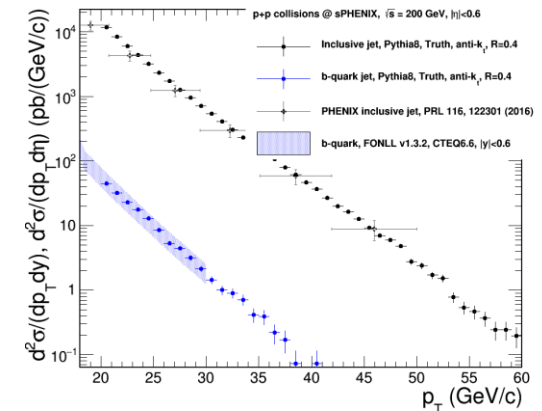
sPHENIX-proposal projection based on fast sim.
 (already updated to Geant4 simulation)



Initial b -jet fraction

Detector requirement on MAPS/MVTX

- ▶ Caveats: there are trade-offs between tail/efficiency/DCA. Important final check is b-jet tagging performance working point: reaching 40% efficiency and 40% purity.
- ▶ Low fake high-DCA tail background
 - *b*-jets are rare (0.1%-1%) object identified via displaced vertex, therefore sensitive to rare large-DCA fake track background.
 - The working point of B-jet tagger is few-sigma above DCA peak, and
 - **Possible specification:** true large DCA track/fake large DCA track > 1:1-1:few for DCA tail integrated from 2-sigma to 1mm
- ▶ Tracking efficiency
 - Efficiency for multi-track tagging algorithm is sensitive to (tracking efficiency)^N
 - **Possible specification:** Require 60% (HFT KPP) – 75% (HFT UPP) single track efficiency $p_T > 1$ GeV/c
- ▶ DCA
 - B-jet DCA requirement is relatively moderate
 - **Requirement:** DCA < 100 μm @ $p_T > 4$ GeV/c (sPHENIX proposal)
- ▶ DAQ output event rate
 - Statistical limited measurement
 - B-jets are jet-structure study based on inclusive jets, require large jet-sample rate
 - **Requirement:** 15 kHz trigger rate to match sPHENIX DAQ



Update in HIJING embedded b-tagger



Past activities:

b-jet tagging – High DCA track counting

► Short history

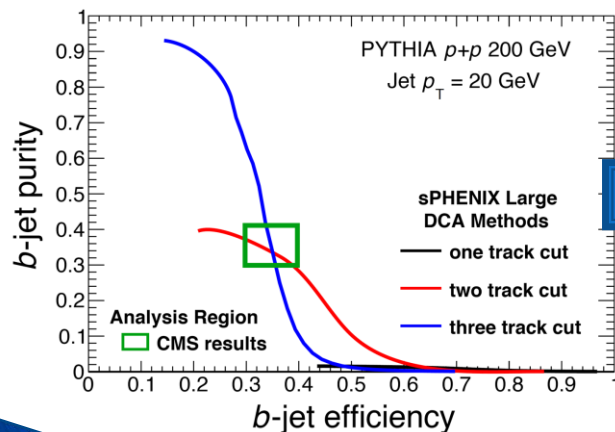
- Dennis and Haiwang implemented track counting tagger in the full Geant4 simulation
- Haiwang produced projection plot in Geant4 simulation.
- Systematically validating the Geant4-based track fit procedure, in order to optimize 3-D DCA and likelihood

► Next

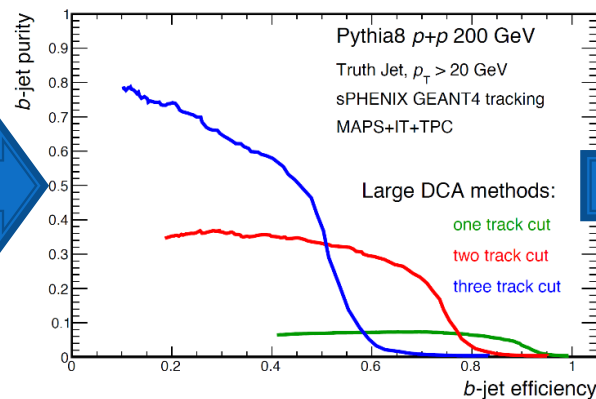
- Reevaluate in HI background with HIJING embedding
- Optimizing cuts to suppress fake off-vertex tracks



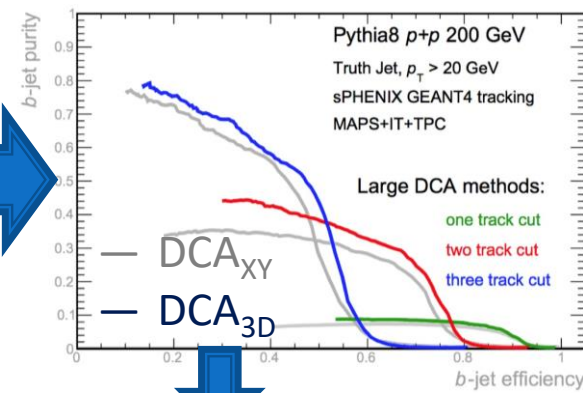
Fast sim in sPHENIX Proposal



Full Geant4 Sim in G4 (DCA_{XY})



Exploring 3-D DCA in G4



From Haiwang's talk

<https://indico.bnl.gov/conferenceDisplay.py?confId=1926>

b-tagging performance in HI

b-jet tagging – High DCA track counting

Update in HIJING embedding:

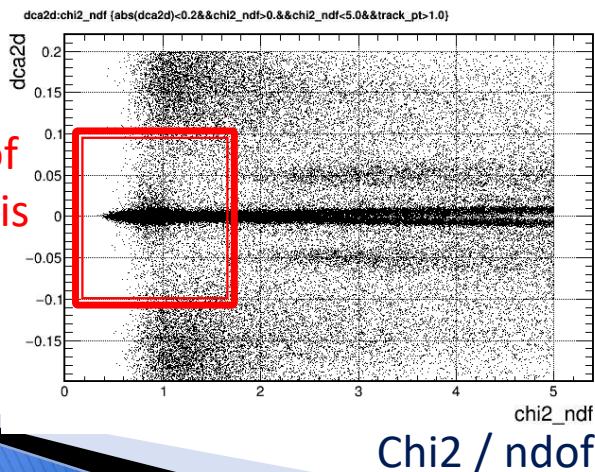
- ▶ Haiwang Yu (NMSU) initiated the study by embedding pythia-8 MB jets into 0-4 fm HIJING background, then go through full tracking Geant4 simulation and reconstruction
- ▶ Two configuration in study
 - Cylindrically modelled MAPS + INTT + TPC (target configuration)
 - 7-layers of MAPS (Same MAPS inner tracker + MAPS outer tracker) as reference of ultimate tracking configuration of very low fake tracking rate but same physics background.



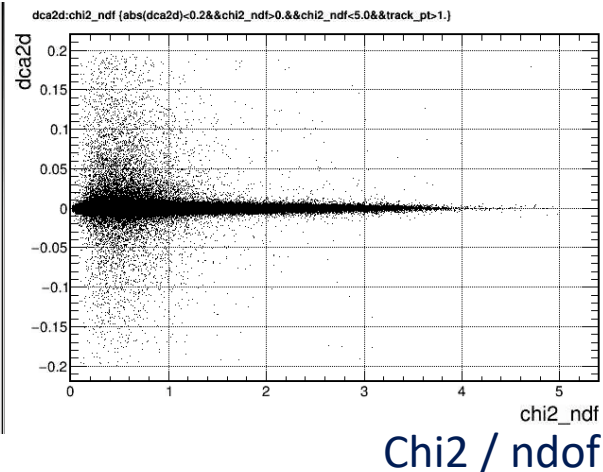
MAPS + INTT + TPC, $p_T > 1$ GeV/c

DCA_2D (cm)

Region of
analysis



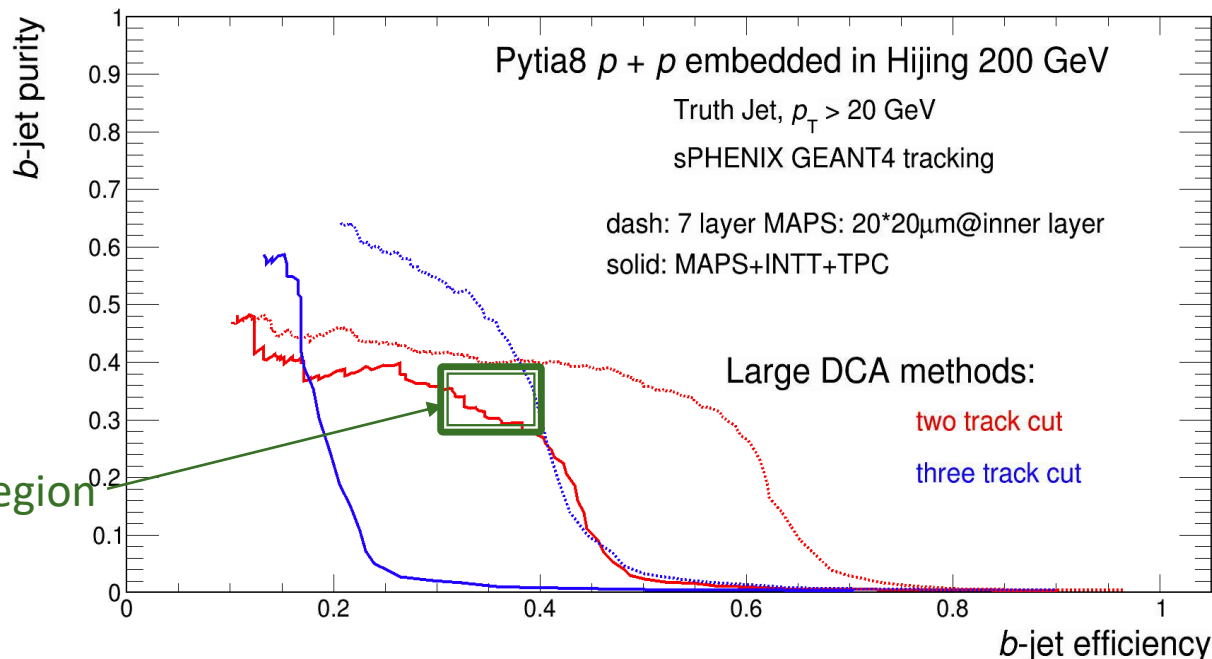
7-layer MAPS, $p_T > 1$ GeV/c



b-jet tagging – High DCA track counting

Update in HIJING embedding:

- ▶ Although still in debugging, initial result show 2/3 good tracks reconstructed comparing MAPS+IT+TPC with 7-layer MAPS
- ▶ This has implication on *b*-jet tagging efficiency of reduced signal efficiency
- ▶ Preliminary results just made minimal
- ▶ Space of improvement: tune cuts, investigating source of large DCA peak and loss of efficiency. Meanwhile, accumulate higher statistics in simulation



More notes on details:

Pythia-8 MB jet
Embed to 0-4 fm Au+Au
Full tracking in Geant4
and reconstruction

Analysis further require

- Track $p_T > 1$ GeV/c
- Track $\text{Chi}^2/\text{ndof} < 1.5$

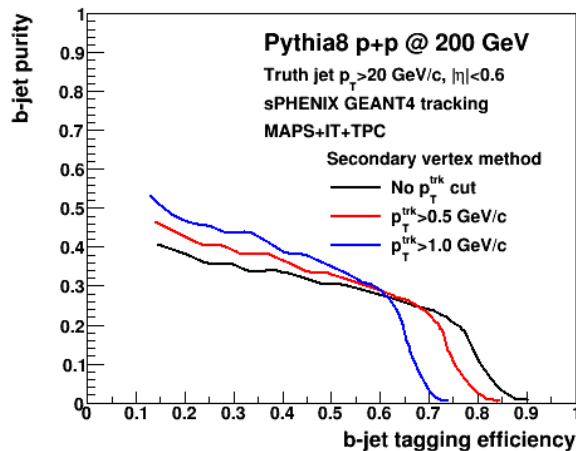
Past activities:

b-jet tagging – Secondary vertex

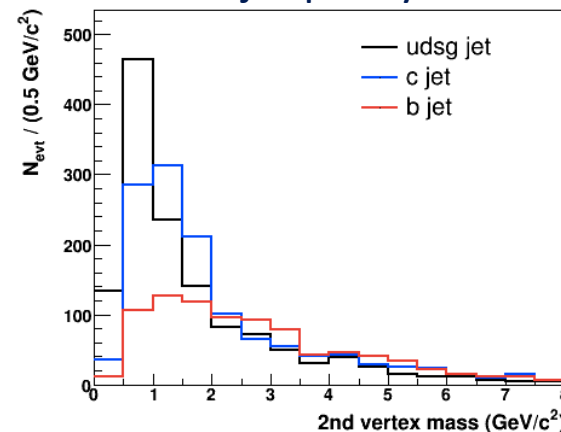
- ▶ Short history
 - Haiwang developed new Kalman filter (GenFit2) with vertex finder integration (RAVE)
 - Sanghoon implemented Secondary vertex finder in jet
 - $p+p$ performance plot used in tracking review
- ▶ Next:
 - Fixing a refitting inefficiency issue (further improve $p+p$ results)
 - Reevaluate in HI background with HIJING embedding



Secondary vertex *b*-tagger



Secondary vertex kinematics fits Data driven *b*-jet purity estimation



From Sanghoon's talk

<https://indico.bnl.gov/conferenceDisplay.py?confId=1928>

b-tagging performance in HI

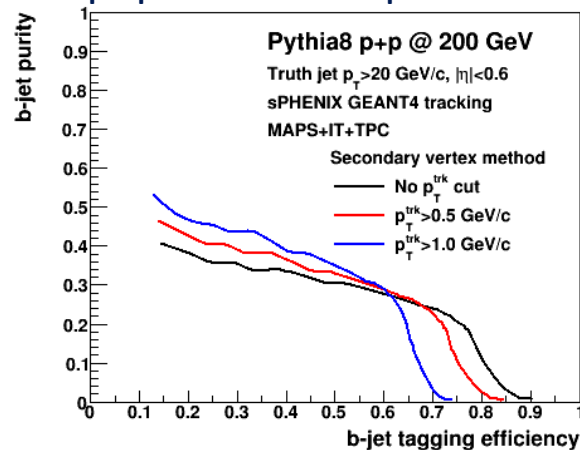
b-jet tagging – High DCA track counting

Updates and HIJING embedding:

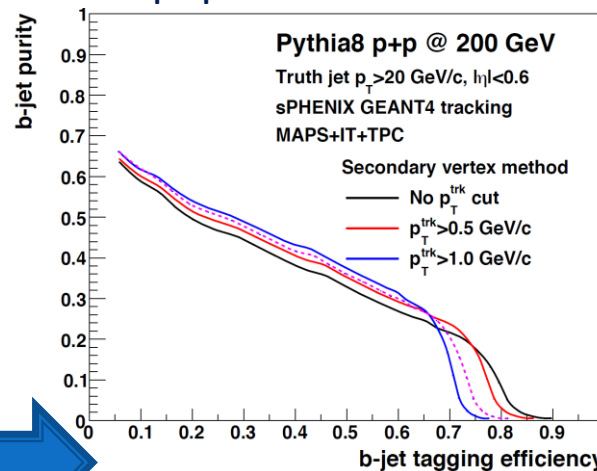
- ▶ Sanghoon and Haiwang found an inefficiency in track fitting software (GenFit2, used by expert only), fix submitted. Analysis show improved performance in p+p
- ▶ Sanghoon also started embedding study with p+p jets embedded in central HIJING events.
- ▶ Working on results for the target tracking configuration of MAPS+IT+TPC



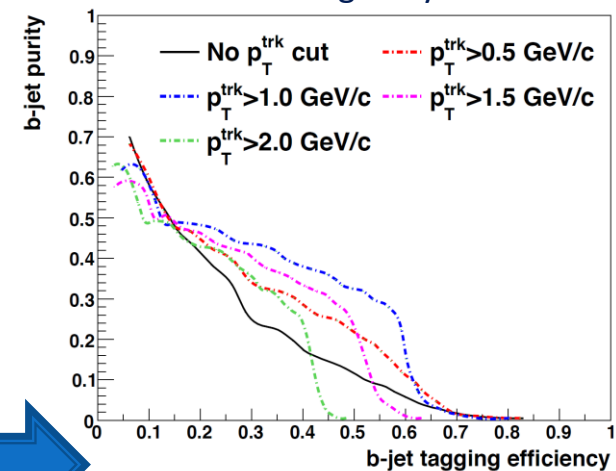
p+p curve in Sept review



New p+p curve after fix



Starting HIJING embedding
Simulated using 7-layer-MAPS



Fitter-inefficiency fix

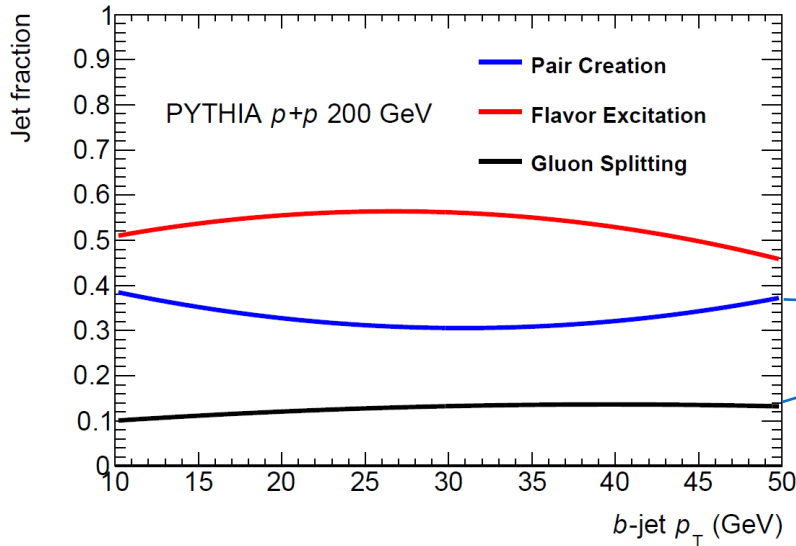
Embedding in central HIJING

Update on b-jet correlations

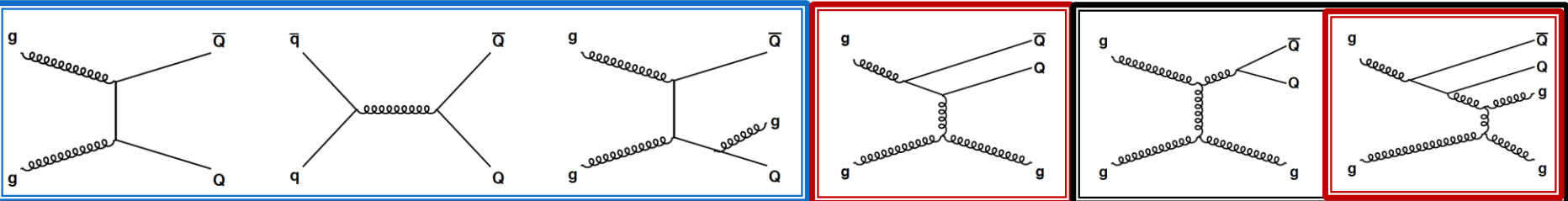
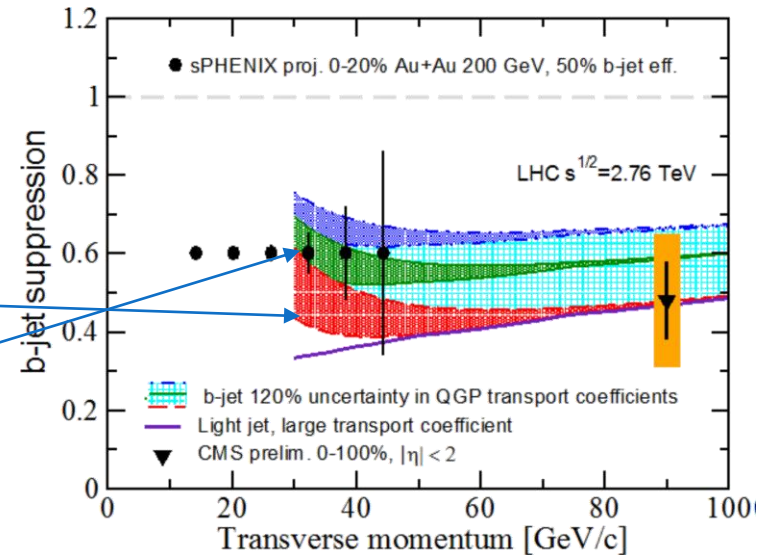


An vulnerability (opportunity) of HF-probes

sPHENIX scientific proposal



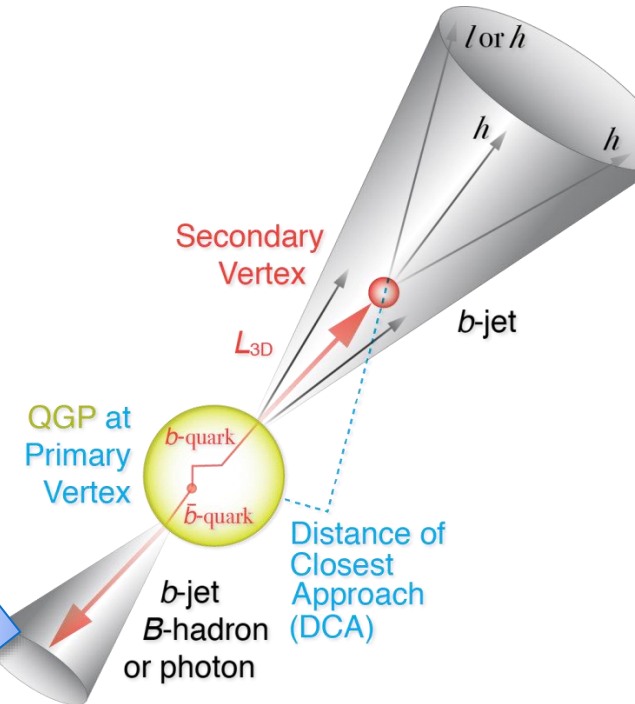
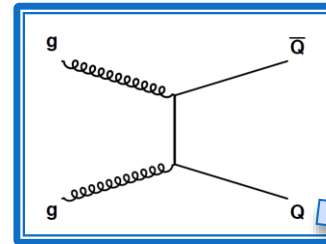
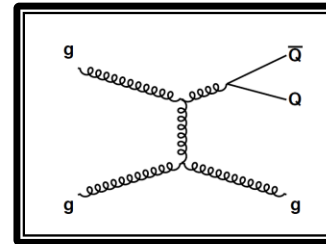
CMS, Phys.Rev.Lett. 113 (2014)
Phys.Lett. B726 (2013) 251-256



Lund String, Eur. Phys. J. C 17, 137–161 (2000)

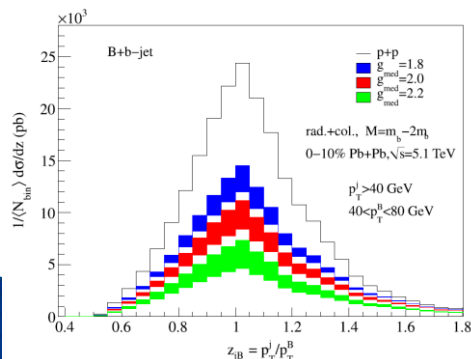
b-quark jet selection: *b*-jet correlation

- ▶ Event topology to select *b*-quark jet
 - *b*-jet in correlation with opposite-going *B*-hadron, *b*-jet and photon
- ▶ sPHENIX provides good acceptance on *b*-di-jet and *b*-jet – non-prompt-*D* correlations
- ▶ Helps on purity of jet and *b*-tagging too
- ▶ Near term goals: fast-sim projection



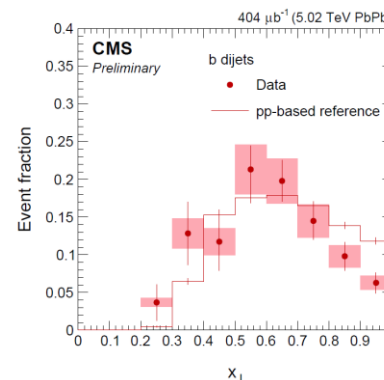
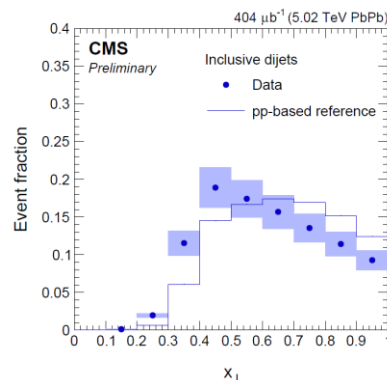
b-jet + *B*-hadron, model

Physics Letters B750 (2015) 287–293



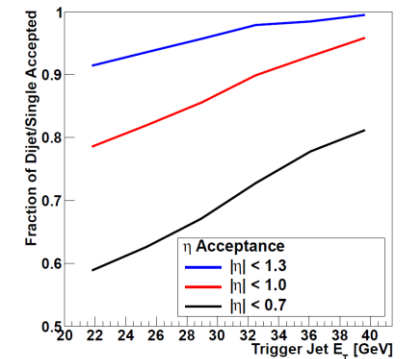
b di-jet, CMS 2016

CMS PAS HIN-16-005



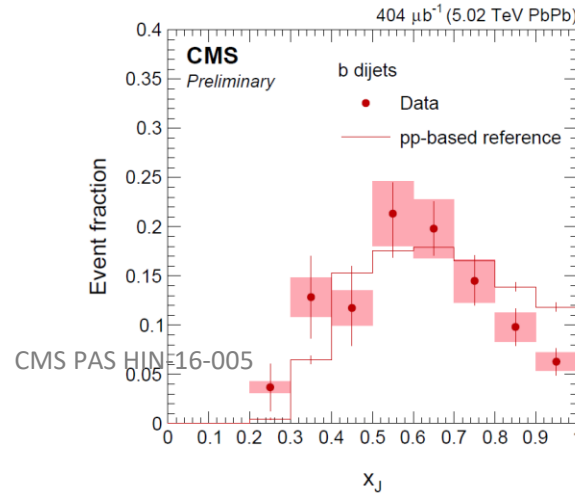
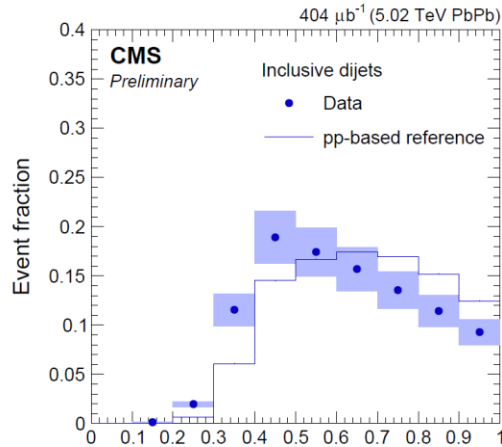
di-jet acceptance in sPHENIX

sPHENIX scientific proposal

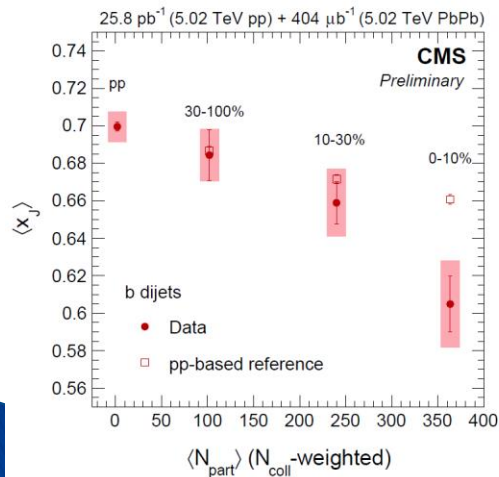


New studies for Di-b-jet asymmetry

With reference to recent CMS TN

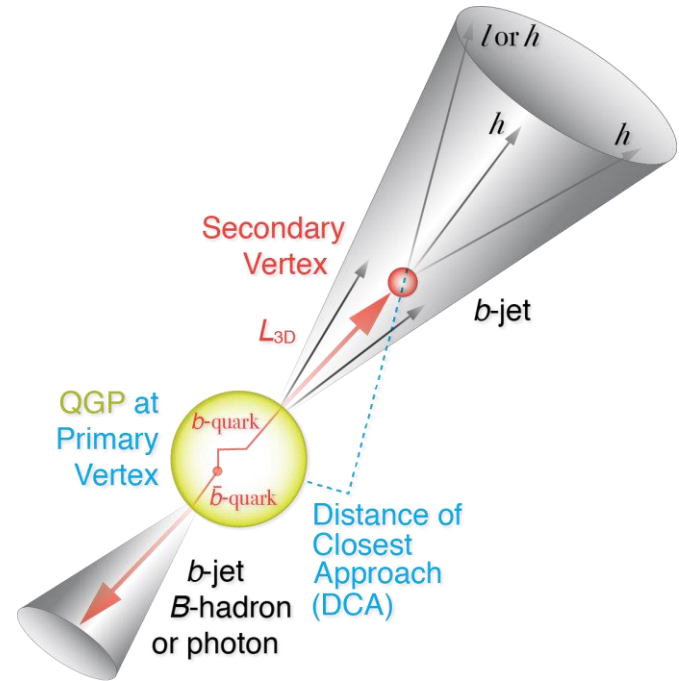


CMS-HIN-16-005



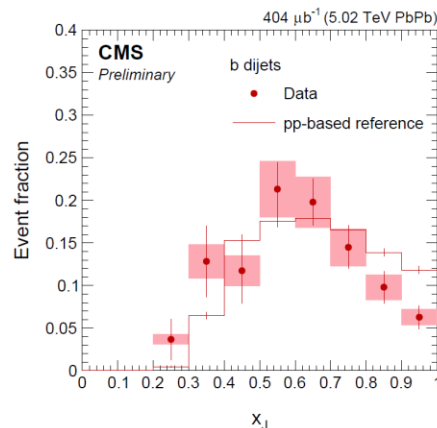
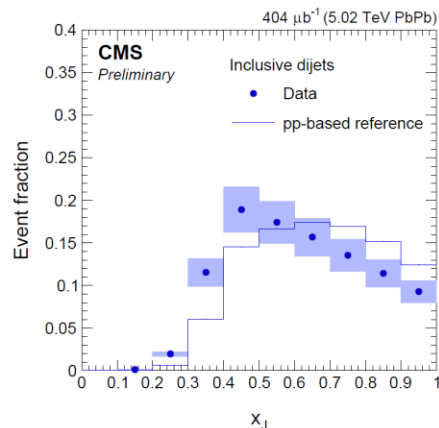
sPHENIX fast sim.

Work started in Jan-2017 workfest
sPHENIX di-bjet asymmetry,
- Darren McGlinchey (UCB)



Di-*b*-jet asymmetry: sPHENIX projection

CMS-HIN-16-005
July 2016

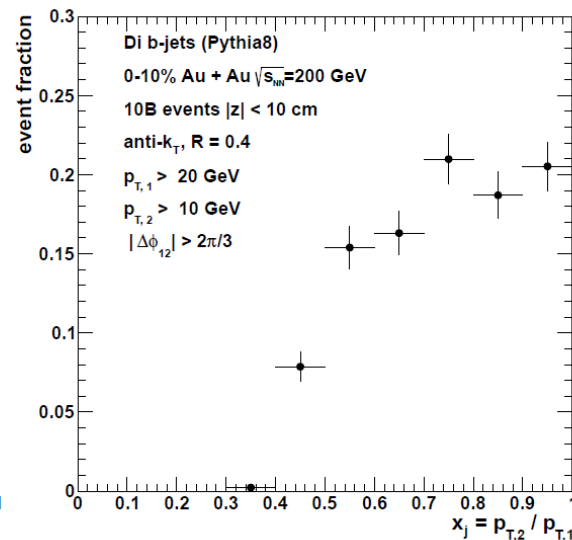
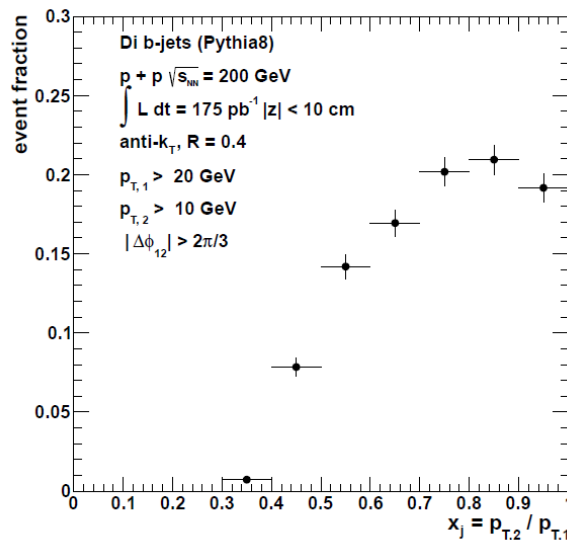


On-going sPHENIX projection

- By Darren McGlinchey (UCB)
- Pythia8 (HardQCDBBar)
- Fast sim. (truth jets)
- Assuming di-*b*-jet tagging perf.
 - Efficiency 50%
 - High purity (100%)
- $R_{AA} = 0.6$ assumed
- sPHENIX proposal lumi. (100B MB)

● For $p + p$ use integrated luminosity of $\int \mathcal{L}_{pp} dt = 175 \text{ pb}^{-1}$

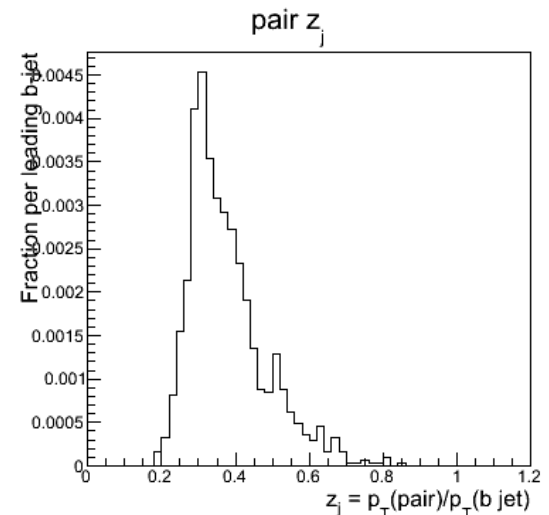
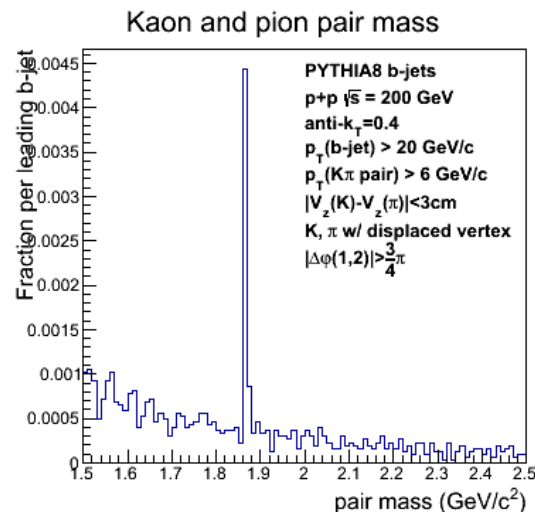
● For 0-10% Au+Au use $n + n$ equivalent luminosity of $\int \mathcal{L}_{nn} dt = N_{ev}^{AuAu} * \langle N_{coll} \rangle / \sigma_{nn} = 10\text{B} \times 962/42\text{mb} = 229 \text{ pb}^{-1}$



More ideas on b -quark jet selection?

Non-prompt D-meson tagging

- ▶ Xuan Li (LANL) also started investigation of correlation of b -jet in correlation of B-meson or a non-prompt D-meson ($\rightarrow \pi + K$)
- ▶ In jet cone: $b \rightarrow B$ hadron fragmentation and modification in medium
- ▶ In opposite hemisphere: suppression of $g/q \rightarrow b\bar{b}$ jet, enhance b -jet tagging purity, p_T -imbalance and constraint energy loss.
- ▶ These initial investigations may lead in a set of projection plots for the full proposal

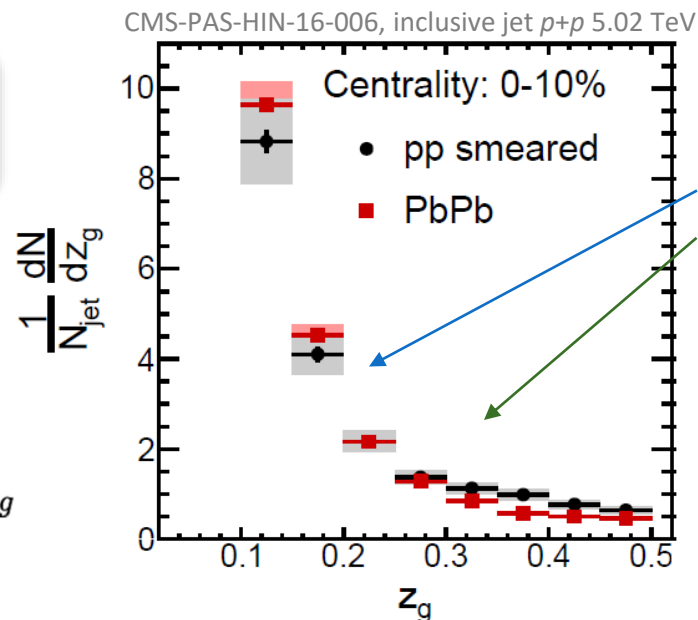
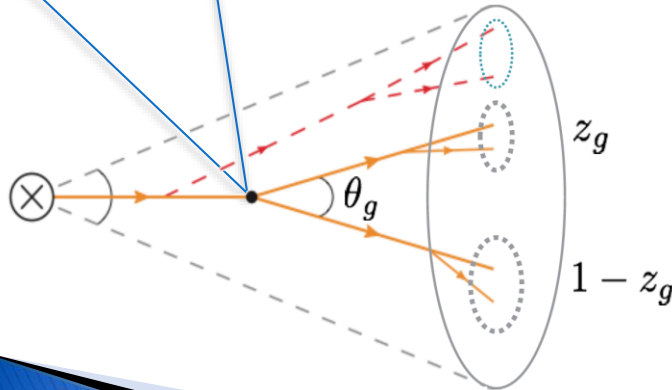


More ideas on b -quark jet selection?

Jet structure tools

- ▶ Jet structure tool developed in HEP adapted in HI field
- ▶ Jet grooming observable z_g to separate b -quark jet and $g/q \rightarrow b\bar{b}$ jet?
- ▶ **Mid-term goals:** in collaborate with JS TG in developing grooming tools – **volunteer welcomed!**

Earliest splitting:
More symmetric for $g/q \rightarrow b\bar{b}$ jet?

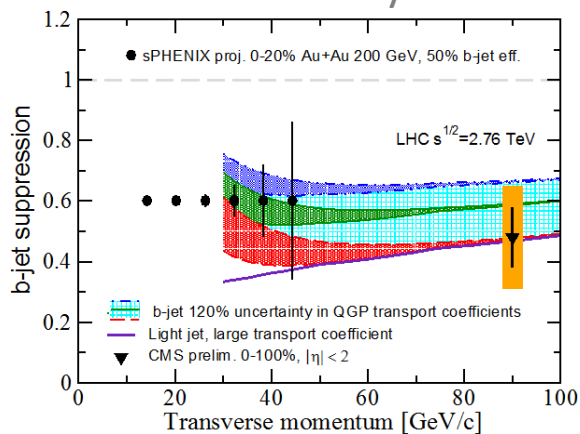


b -quark jets ??
 $g/q \rightarrow b\bar{b}$ jet ??

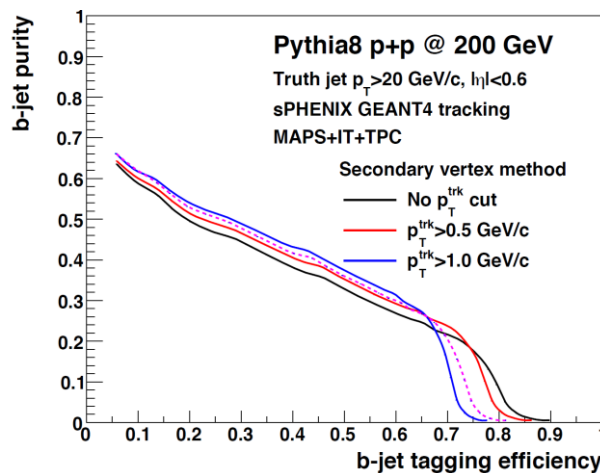
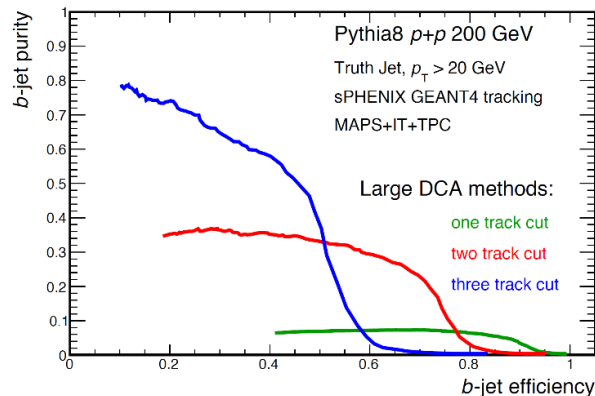
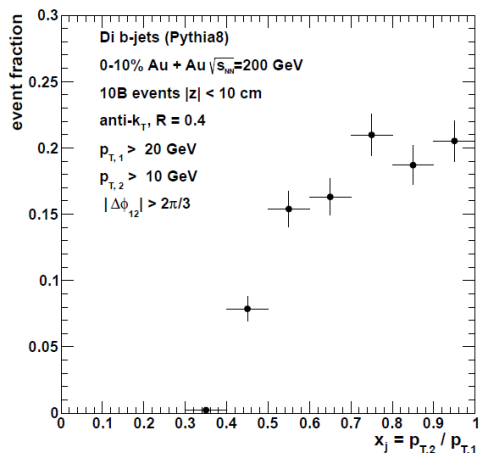
A+A Modification
would enhance
 $z_g \sim 0.5$ (i.e. $g/q \rightarrow b\bar{b}$
less suppressed)?

Plots for MAPS pre-proposal and QM17

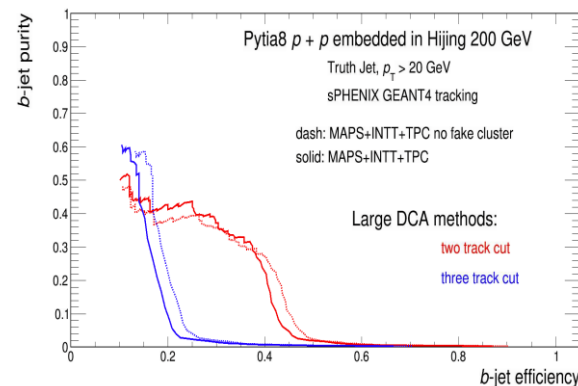
Need to update to the final
int. lumi. + theory curves



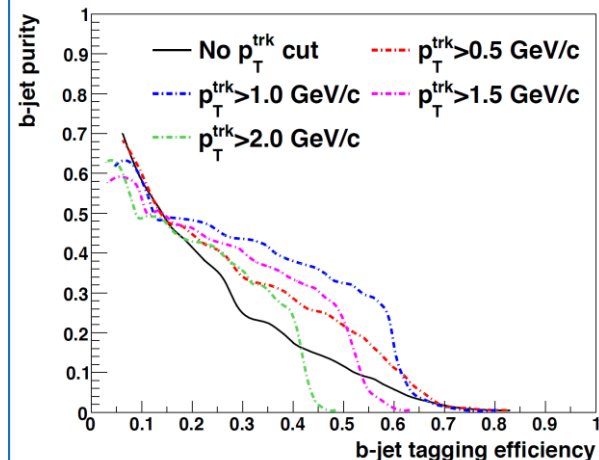
New: di-*b*-jet asymmetry



Still preliminary: HIJING-embedded



Place holder for HIJING-embedded



Observable Projections

b-jet tagger/track counting

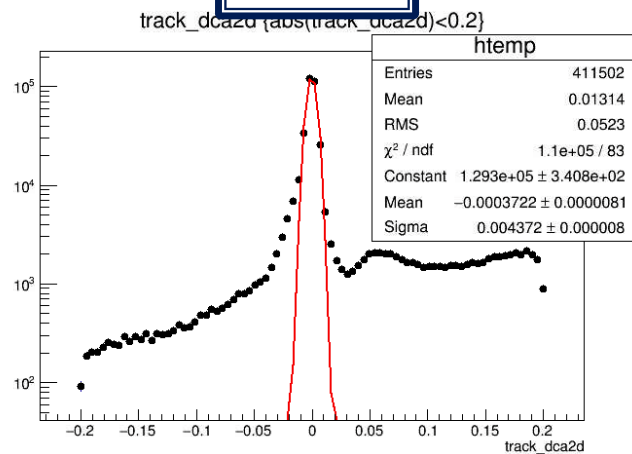
b-jet tagger/2nd-vertex



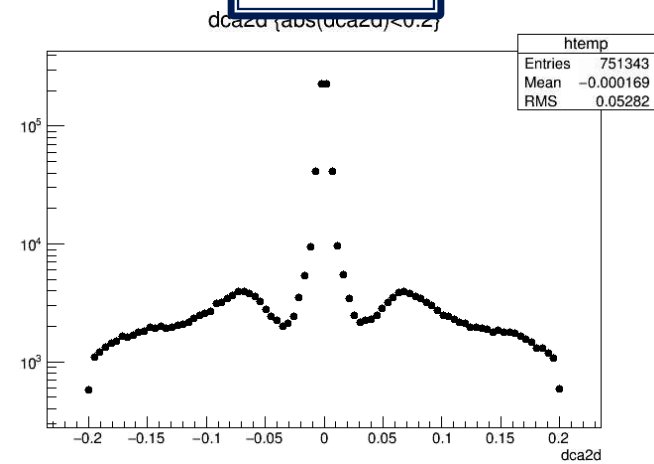
Extra information



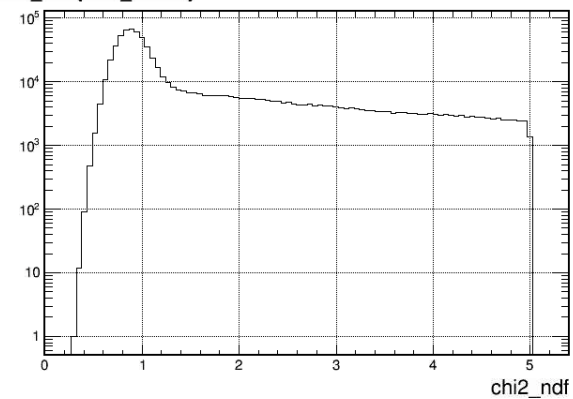
Original



Refitting



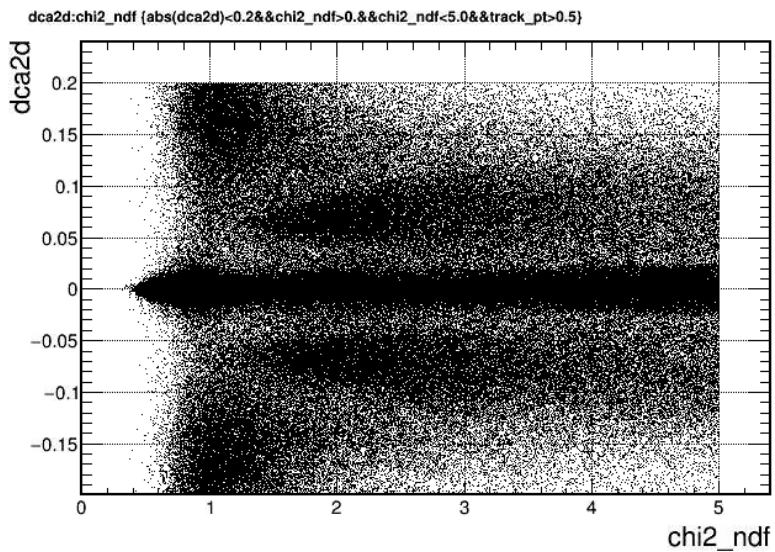
chi2_ndf {chi2_ndf>0.}



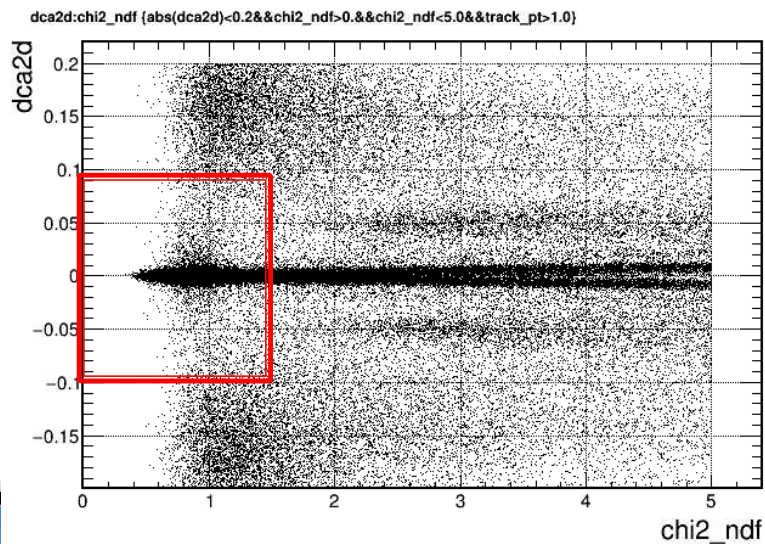
Track selection

MAPS+INTT+TPC

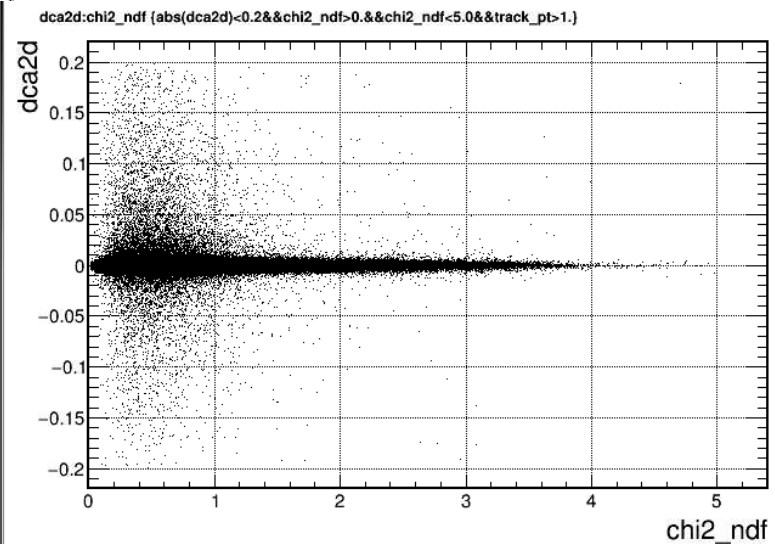
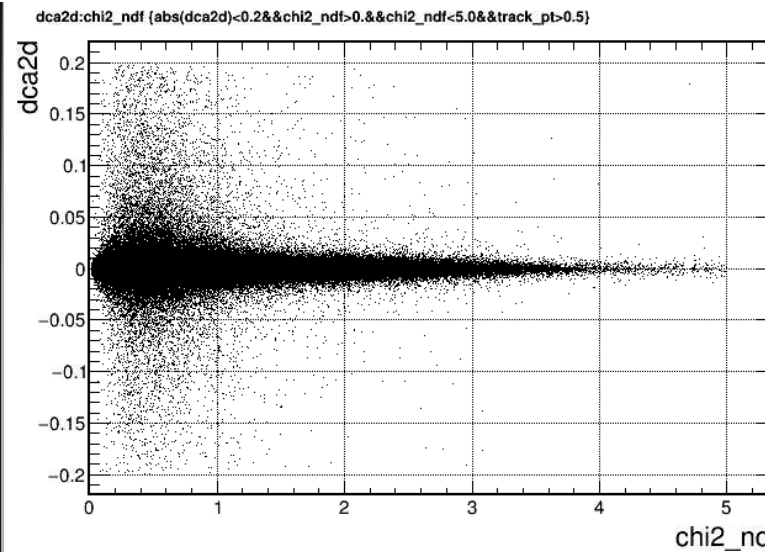
$p_T > 0.5$



$p_T > 1.0$



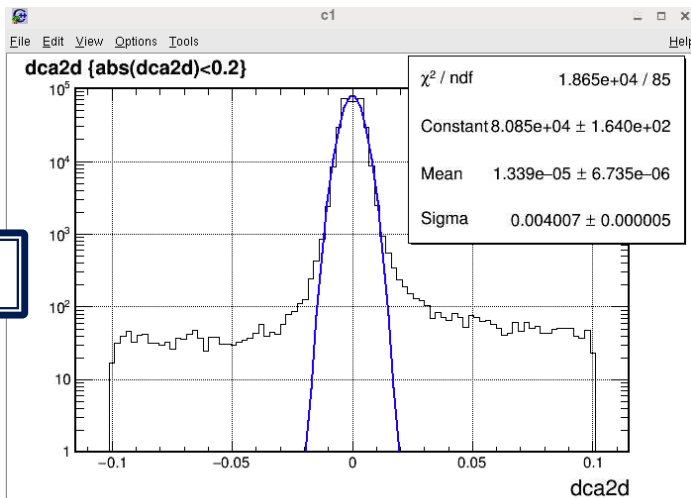
7-Layer MAPS



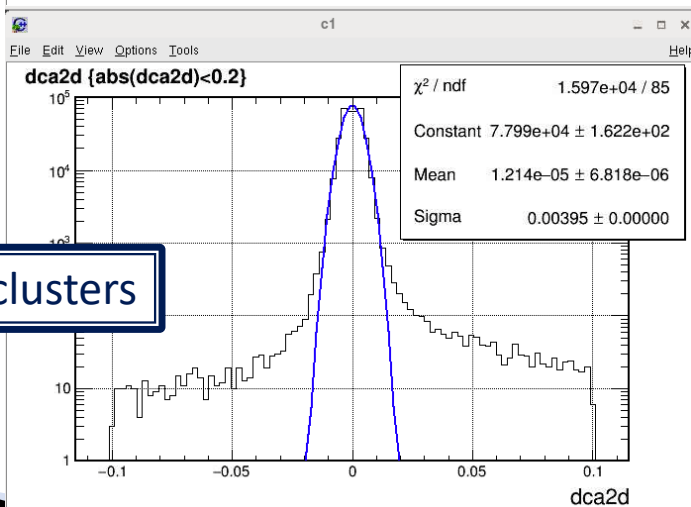
Track selection cont'd

MAPS+INTT+TPC

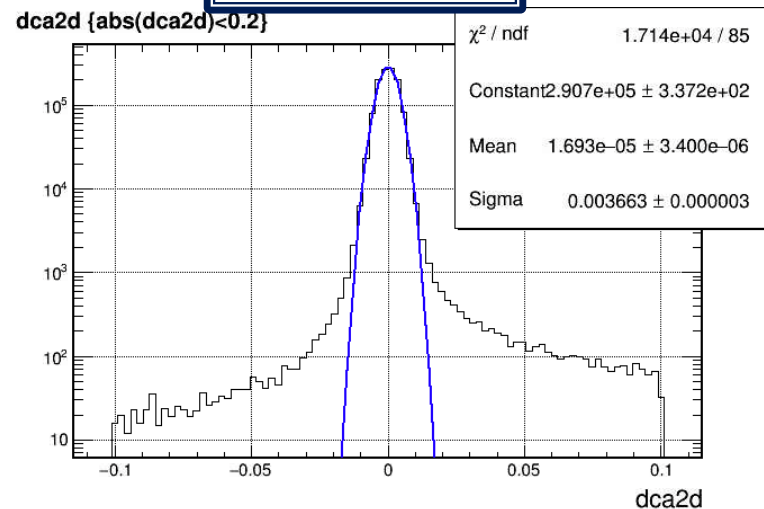
All tracks



No fake clusters



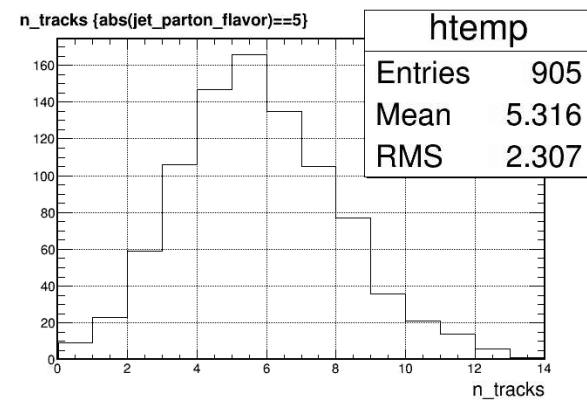
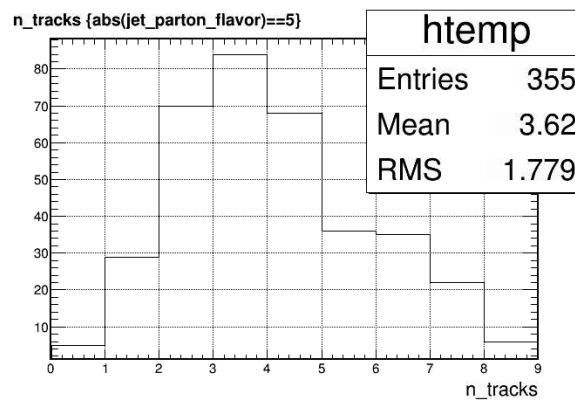
7-Layer MAPS



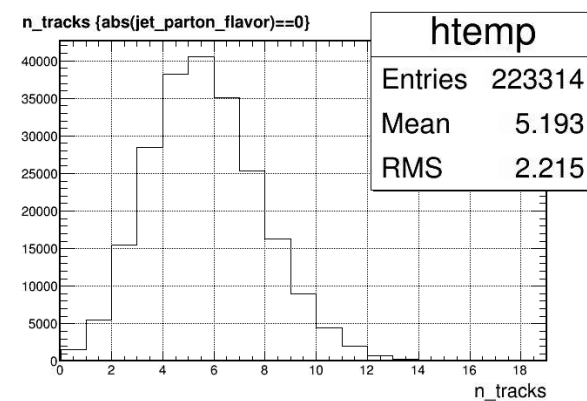
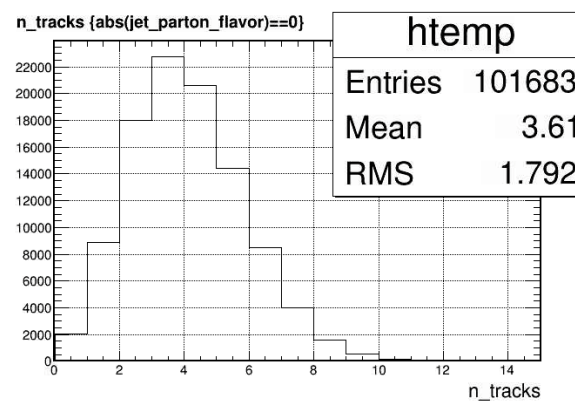
MAPS+INTT+TPC

7-Layer MAPS

b-jet

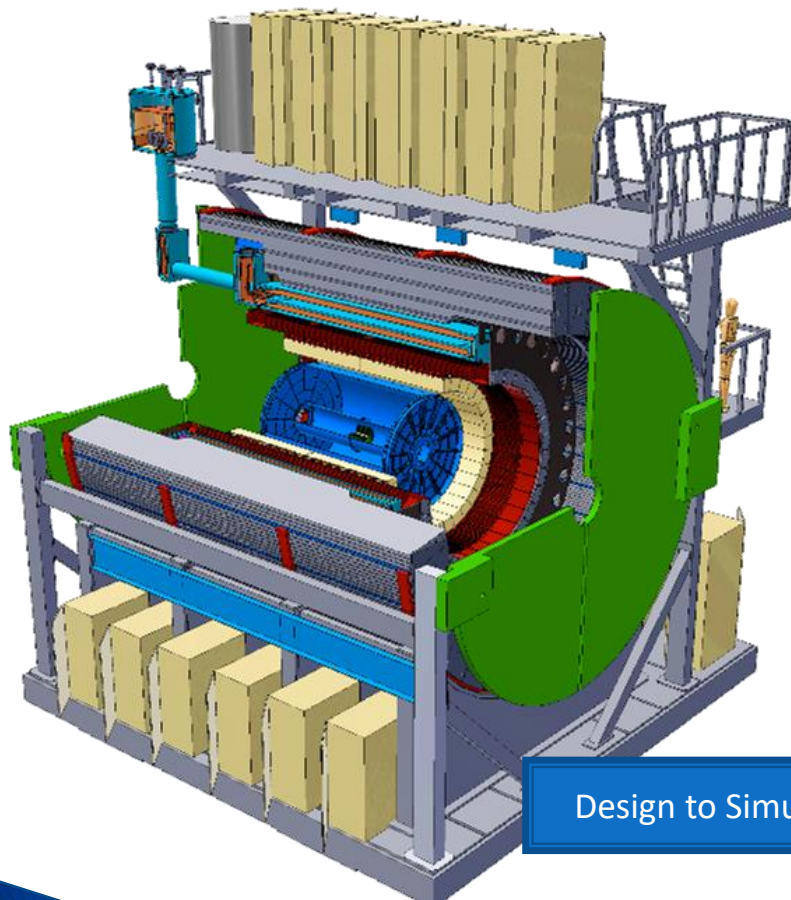


l-jet

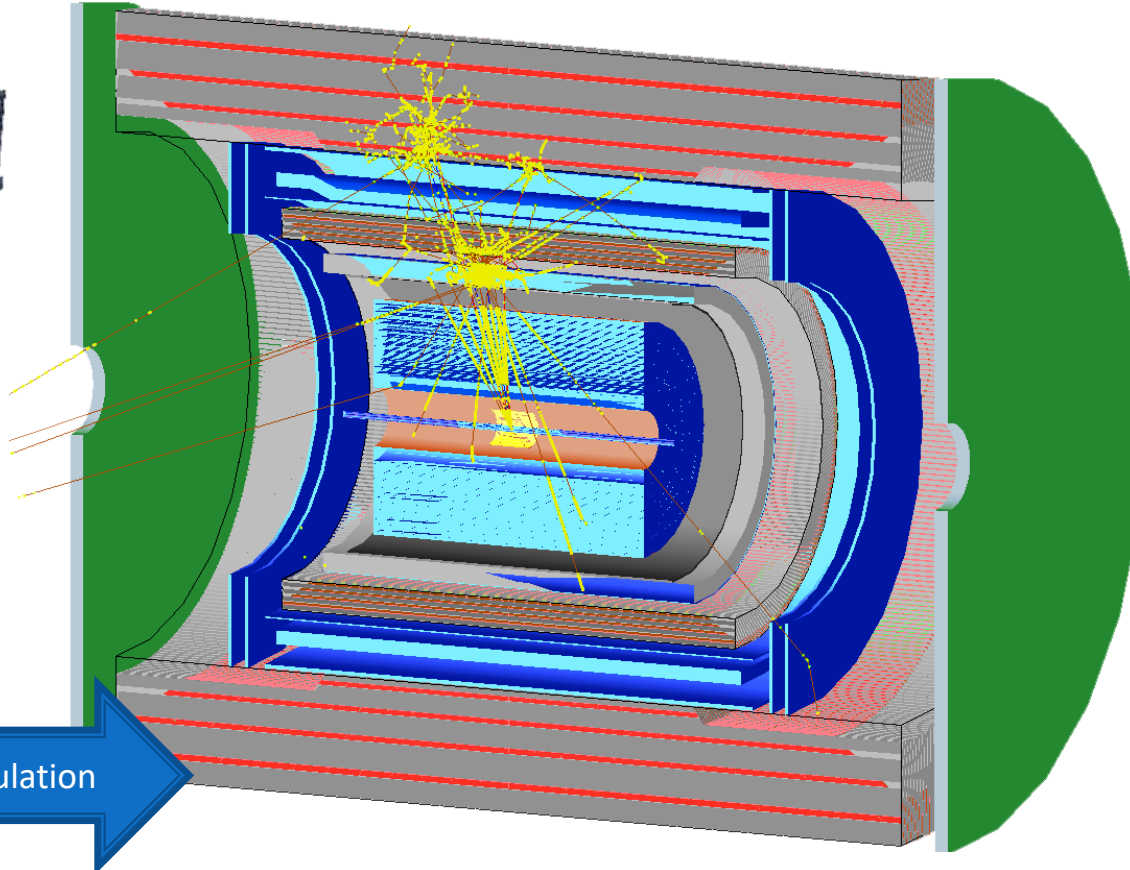


b-jet simulations, drawing to Geant4

sPHENIX Geant4 simulation of $p_T=30$ GeV/c B^+ -hadron

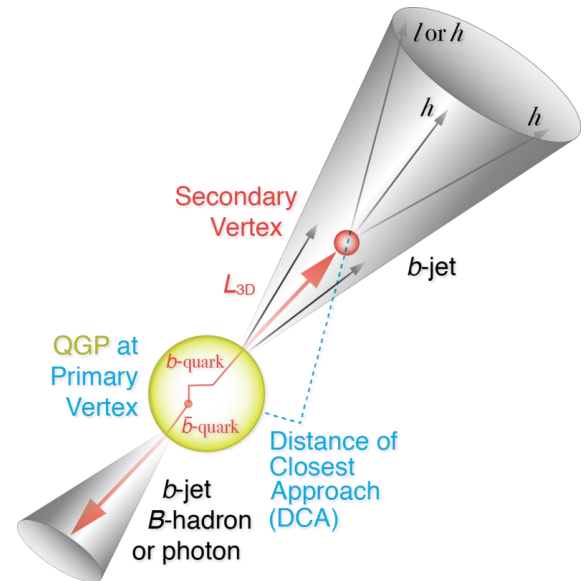
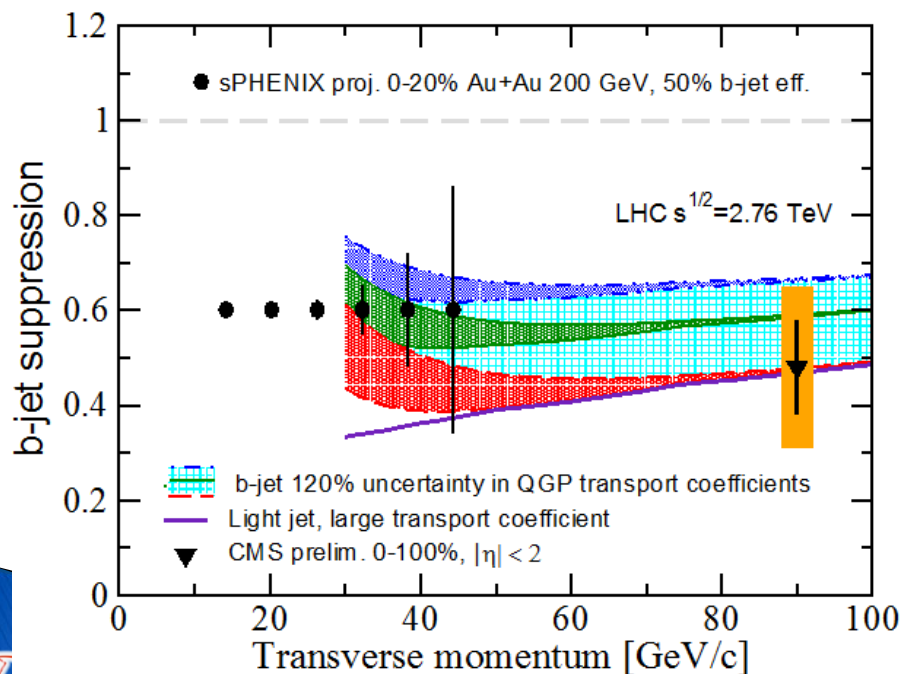


Design to Simulation



Luminosity counting

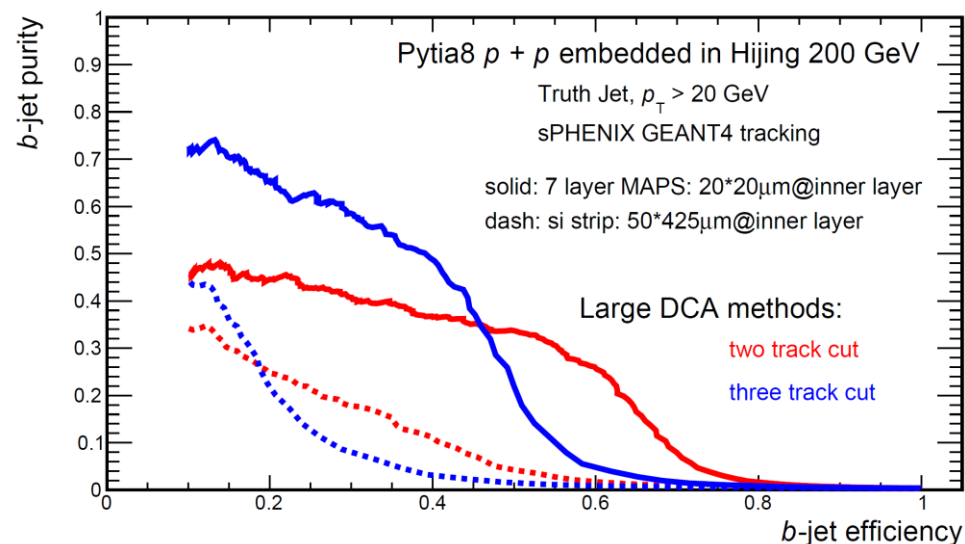
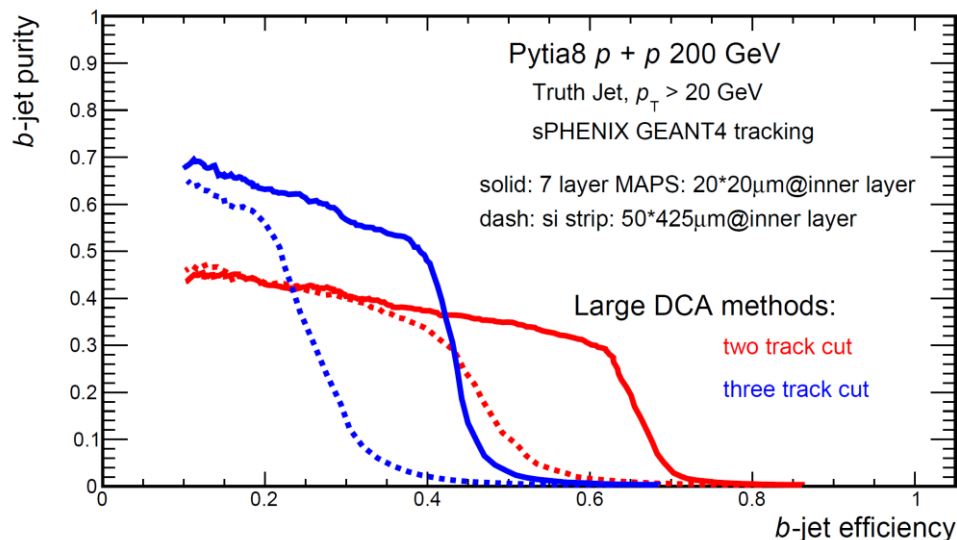
- ▶ Current RAA plot assumed 200B MB Au+Au in $|z| < 10\text{cm}$
 - 100B MB Au+Au in $|z| < 10\text{cm}$ assumed for sPHENIX proposal
 - 200B MB Au+Au in $|z| < 10\text{cm}$ following updated CAD projection
 - Will follow the final luminosity number determined by collaboration for QM17 - Gunther
- ▶ For MAPS proposal, we need updated model R_{AA} for RHIC energy



New plots from track counting

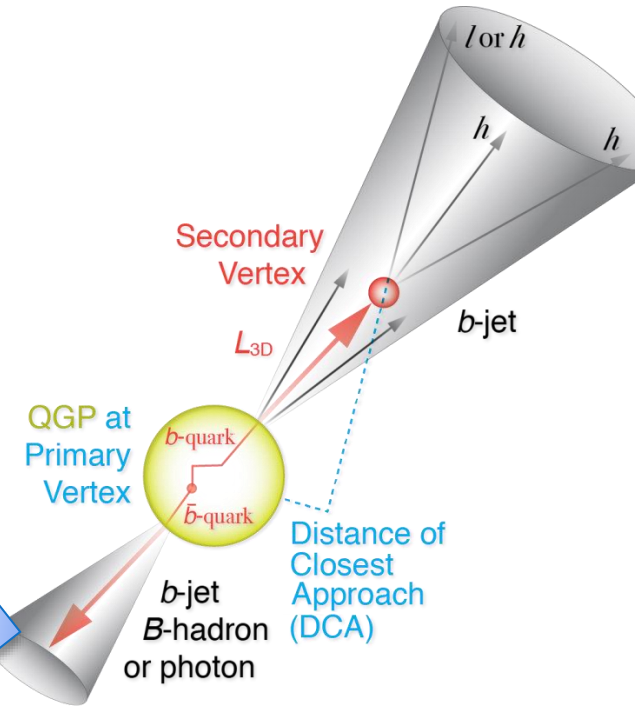
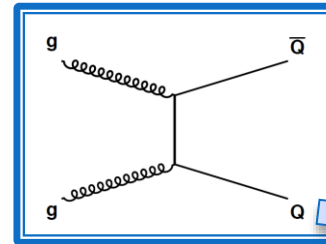
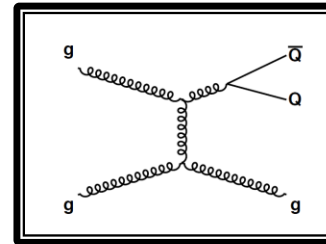
- ▶ Answering two main questions in this workfest:

1. How we do in HIJING
2. What if we use other technology



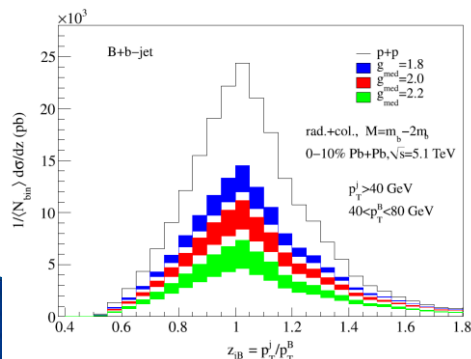
b-quark jet selection: *b*-jet correlation

- ▶ Event topology to select *b*-quark jet
 - *b*-jet in correlation with opposite-going *B*-hadron, *b*-jet and photon
- ▶ sPHENIX provides good acceptance on *b*-*di*-jet and *b*-jet – non-prompt-*D* correlations
- ▶ Helps on purity of jet and *b*-tagging too
- ▶ Near term goals: fast-sim projection



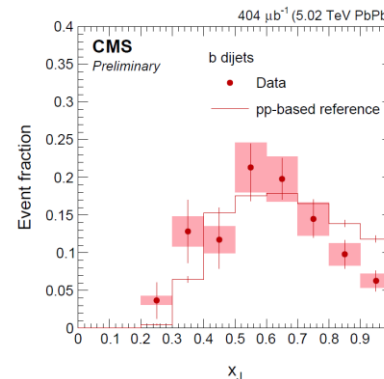
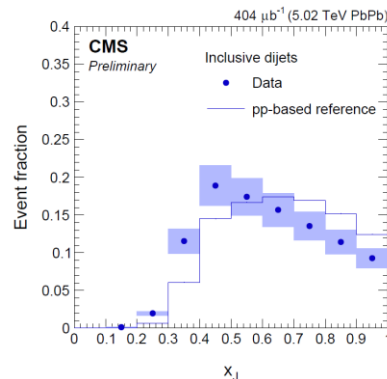
b-jet + *B*-hadron, model

Physics Letters B750 (2015) 287–293



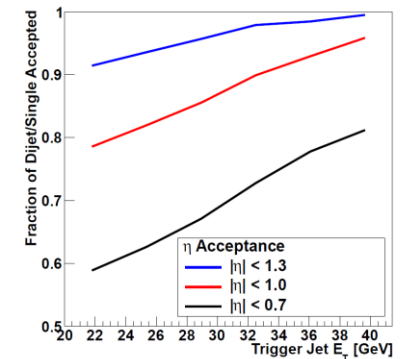
b di-jet, CMS 2016

CMS PAS HIN-16-005

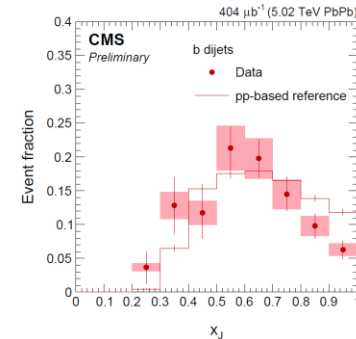
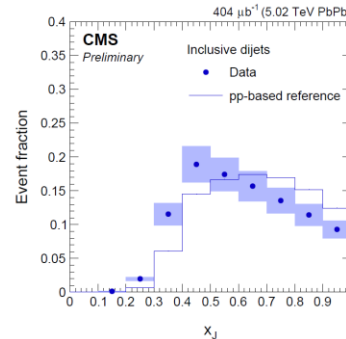
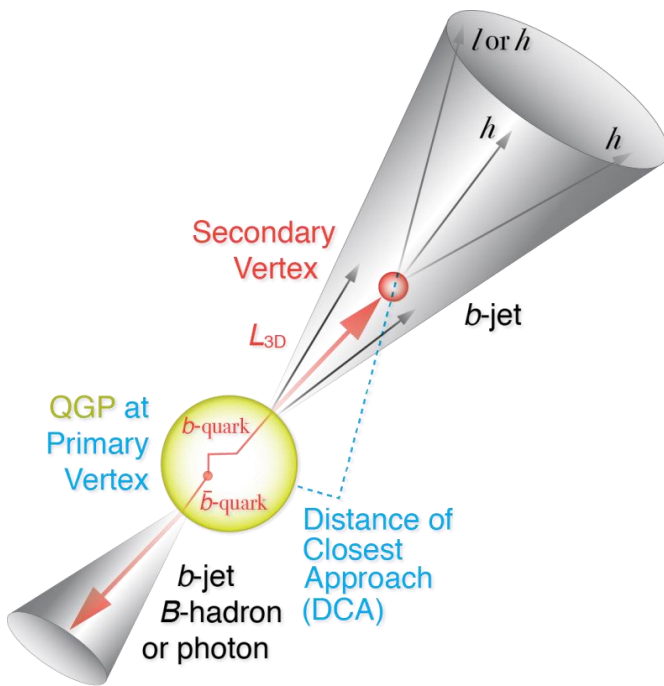


Inclusive *di*-jet acceptance in sPHENIX

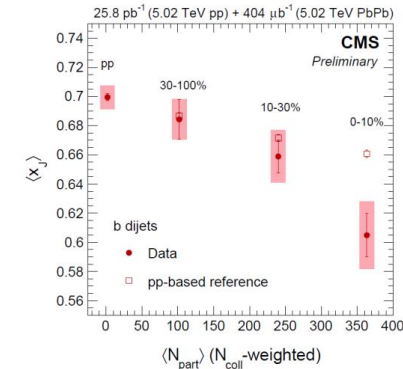
sPHENIX scientific proposal



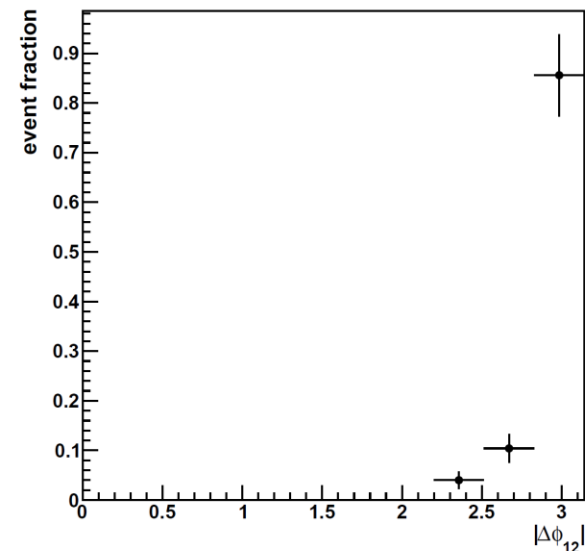
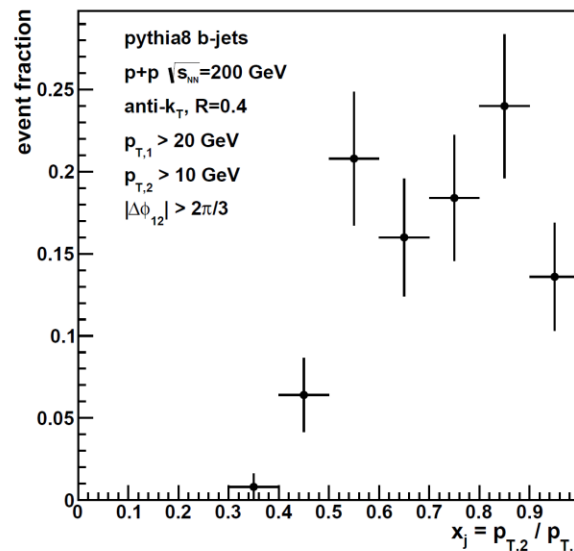
New plots from Di-b-jet asymmetry



CMS PAS HIN-16-005

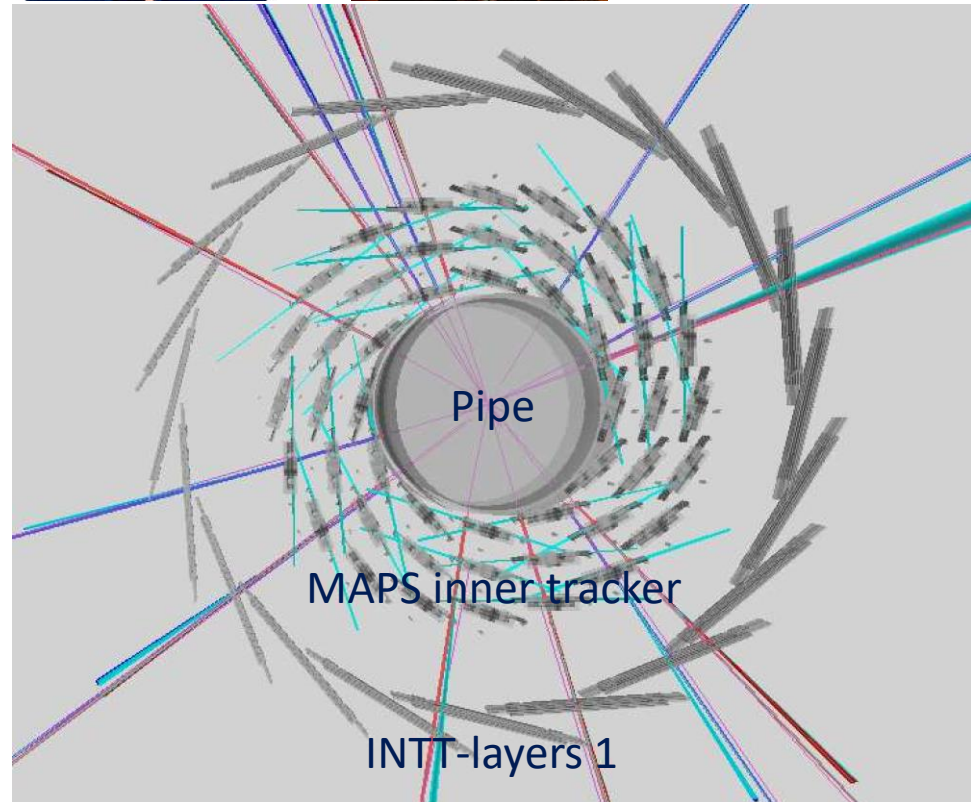


Started in workfest : sPHENIX di-bjet asymmetry,
This plot is preview: fast-sim, hardQCD-B, NOT scaled to lumi
- Darren McGlinchey (UCB)



Silicon ladder setup

- ▶ Implementing realist geometry in laddered silicon detectors
- ▶ Base-code in nightly build
- ▶ Tuning on going for
 - INTT ladder thickness
 - Kalman filter to interface with geometry

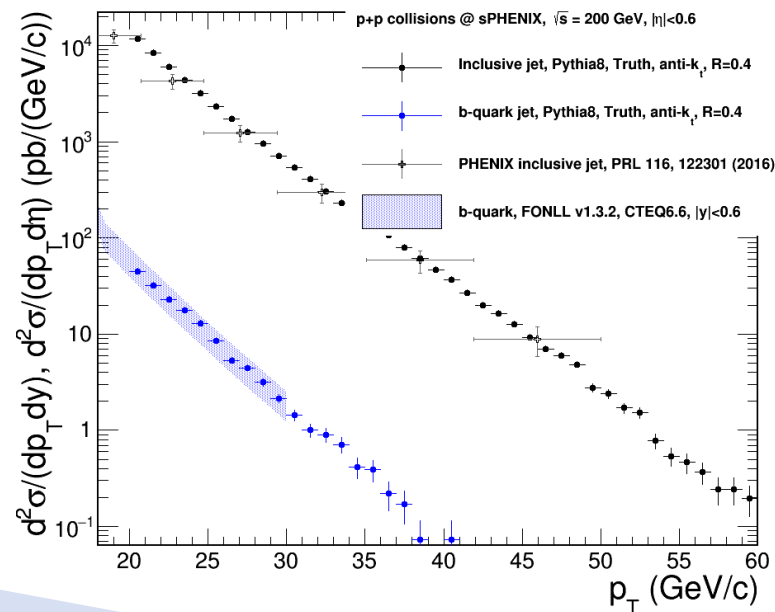


Simulation resources

- ▶ Currently we separate jet and b-tagging simulations to help speed up simulation. Need to verify factorization in the next stage
- ▶ Simulation setup used in analysis:
 - Tracking simulation in p+p in MAPS+IT+TPC (few minute / event)
 - Tracking simulation in HIJING + embedding for 7-layer MAPS (few minute / event, used for initial tunings) and for MAPS+IT+TPC (1-hour / event, use for performance plots)
- ▶ In developments
 - Silicon detectors in ladder geometry <- make available soon?
 - Pile up simulation <- make available soon?
 - TPC distortion corrections

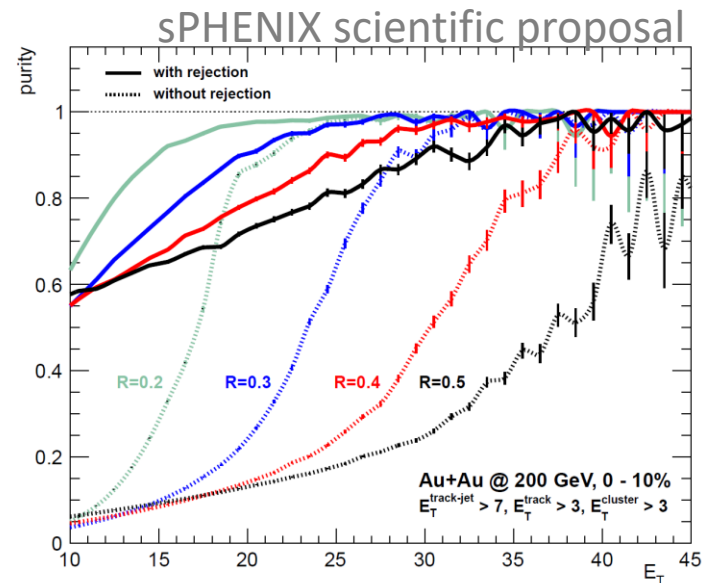
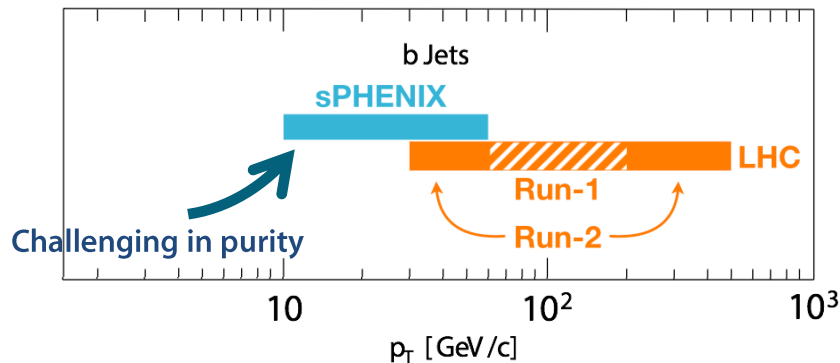
Jet flavor definition tools

- ▶ **Unifying truth definition** and jet sample generations
 - Based on Dennis' work defining a truth tagging module run on MB events to synchronize *B*-jet definition and yield between analyzers
 - Two options provided in defining truth jet by matching *b*-quark in jet (CMS definition) or by matching *B*-hadron in jet (proposal definition)
 - Available on GitHub:
<https://github.com/sPHENIX-Collaboration/analysis/tree/master/HF-Jet/TruthGeneration>
- ▶ In collaboration with TS TG: Plan to be generalized to light-parton tagging and parton interaction channel categorizations
- ▶ **Mid-term goal**: cross checked with data and NLO generators



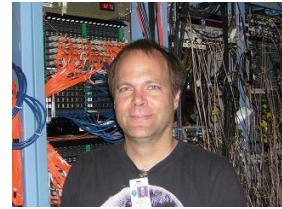
Jet finding and fake rejections

- ▶ HF-jet are based on jet, relying on jet finding development lead by JS TG
 - Emphasis on purity and reach to lowest-possible- p_T jet, where mass effect is maximized
 - No statistics for b -jet beyond $p_T > 50$ GeV/c
- ▶ HF-jet specific: response in detector for b -favored jet, unfolding and media modification
 - Require join study with JS TG in term of experience and toolkit developments



HF-jet TG high priority longer-term tasks

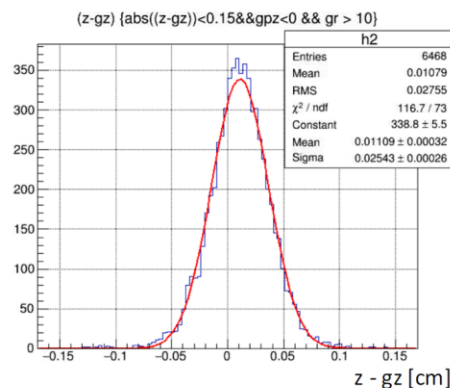
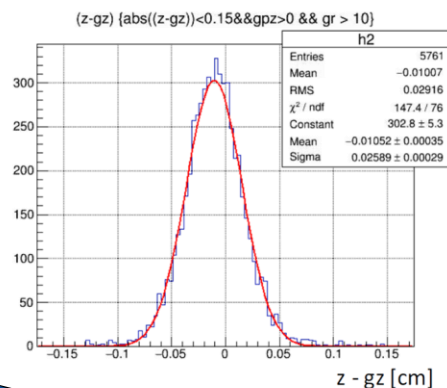
- ▶ Goal: realistic study of HF jet performance in sPHENIX simulation and reconstruction.
- ▶ High priority development tasks :
(current developers and **your help/ideas welcomed!**)
 - Realistic implementation in Geant4
 - Tony F./Gaku M./Chris P.: merged to main repository last week. Validating for general use.
 - Generalized Kalman filter
 - Haiwang Y./Chris P., ready, used in analysis, improving details
 - Multi-vertexing/ b -tagging via secondary vertexing in jet
 - Sanghoon L./Haiwang Y.: ready, used in analysis, push towards HI analysis
 - b -jet tagging: Track Counting
 - Haiwang Y./Dennis P.: ready, used in analysis, push towards 3-D DCA and HI analysis
 - b -jet tagging: Soft Lepton Tagging, exploratory
 - b -quark jet selection: B -Meson Tagging. Exploratory, volunteers from LANL and LBNL
- ▶ Area of overlapping with to other TG groups
 - JS TG: Jet detection / modern jet structure tools / event and jet flavor tagger
 - Quarkonia TG: tracking development/ HF-meson detection



Highlight recent activities: DCA_x

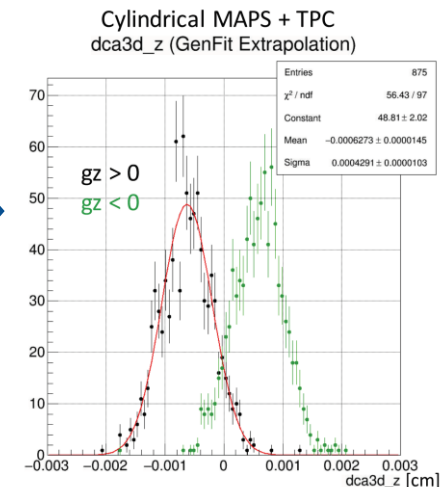
- ▶ Both methods highly depending on quality of DCA
- ▶ Haiwang *et al* developing capable Kalman filter (GenFit2), expand to DCA_{3D} and use it to validate
- ▶ Not only-MAPS matters for DCA
 - Consider use z-sensitive strip in subset layers of INTT?
 - Important to develop and verification as a whole system downstream of clustering

Small (but systematic) bias in TPC cluster z
TPC software group is fixing this problem



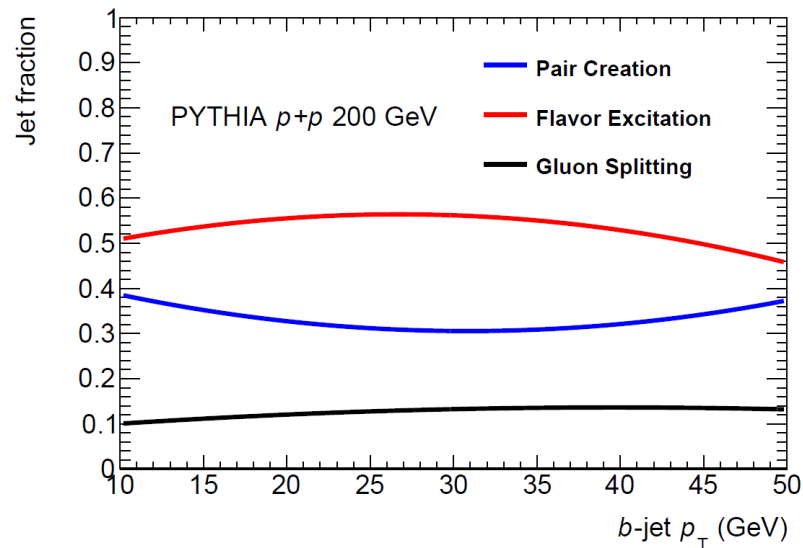
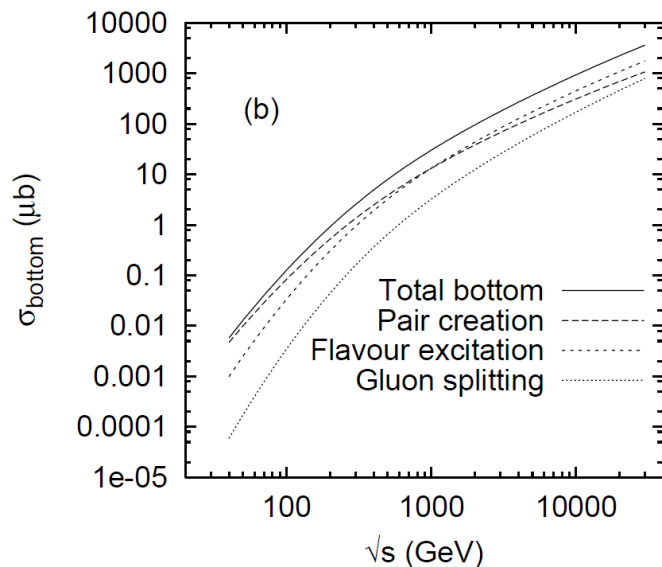
Kalman
fit with
MAPS

Non-negligible bias in DCAz

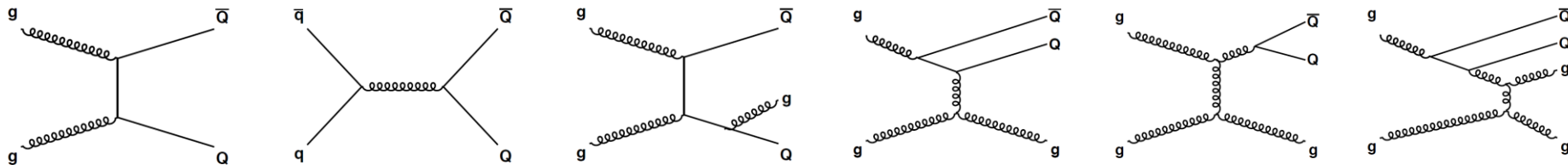


From Haiwang's talk <https://indico.bnl.gov/conferenceDisplay.py?confId=1940>

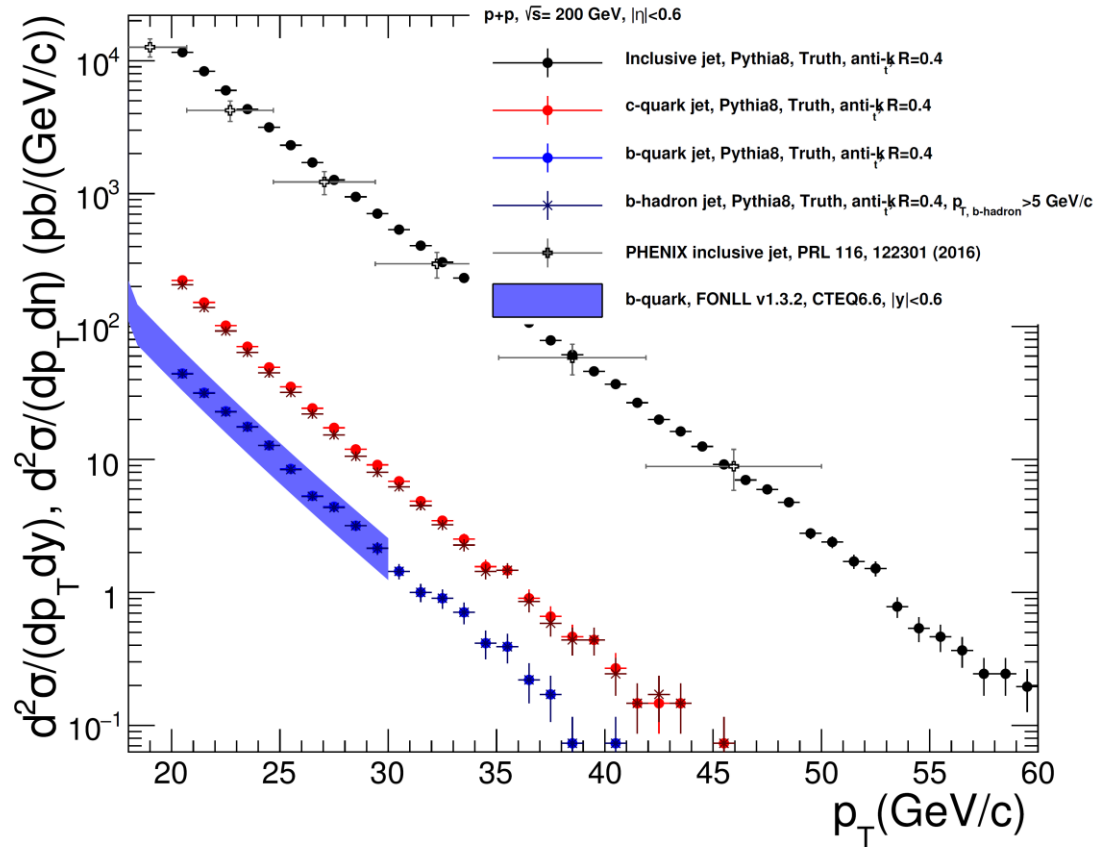
b-jet fraction in LUND family estimation



Lund String, Eur. Phys. J. C 17, 137–161 (2000)



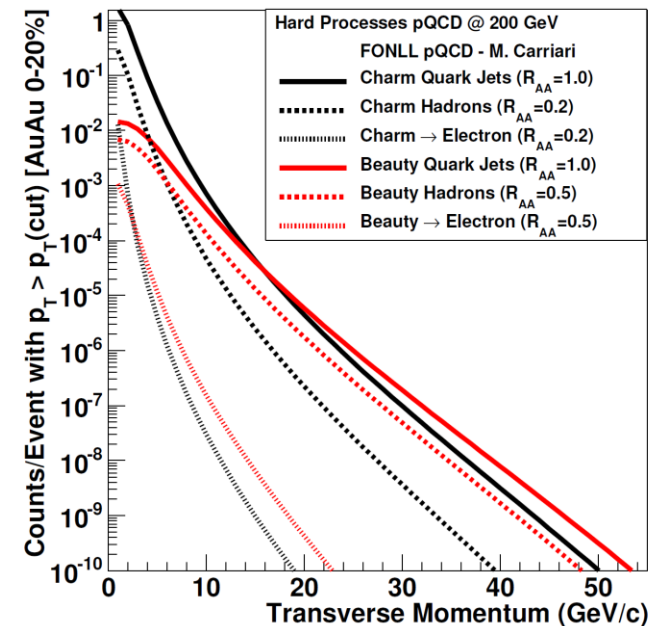
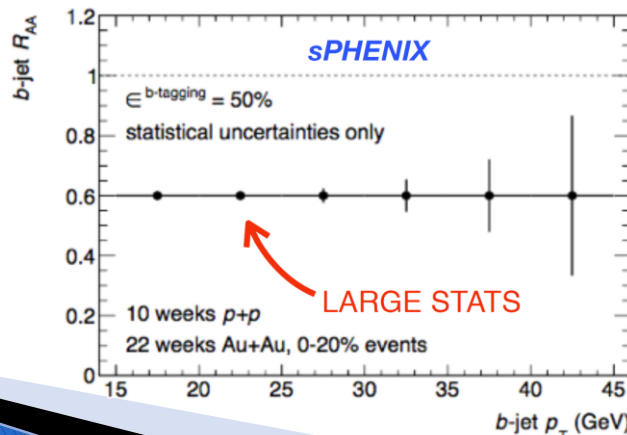
Cross section from pythia8



B-jet tagging

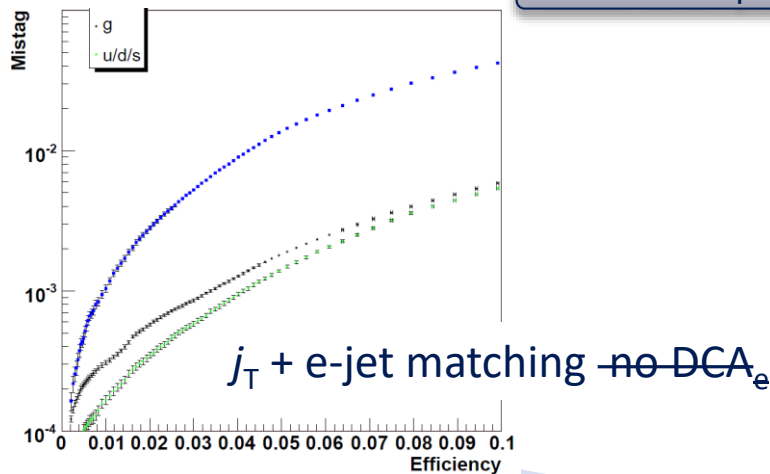
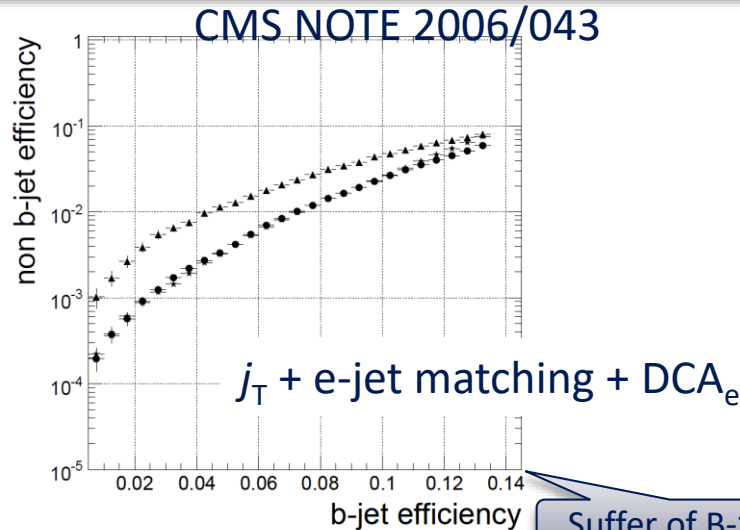
– Decay lepton tagging

- ▶ None-photonic lepton has been a successful tool in studying heavy quark behavior in QGP
- ▶ Given a jet detected, lepton tagging in or near the jet cone could enhance HF jet fraction due to larger fraction of $B(->d)->e$ decay than $h->e$ decays.
 - Benefit:
 - Not necessarily require a DCA capability. No additional sPHENIX detector required
 - (Largely) orthogonal to and cross check life-time-based B tagging: e.g. DCA-track-counting and Secondary vertex mass methods
 - Cost: $B->e$ branching ratio ($\sim 20\%$), electron identification efficiency, (b-tagging efficiency)
- ▶ Challenge:
 - Exploring possibility @ RHIC energy
 - Signal/background ratio and
 - Optimization both in $j_{T,e}$ and DCA_e
 - Statistics



Decay lepton tagging - CMS studies (muon tagging)

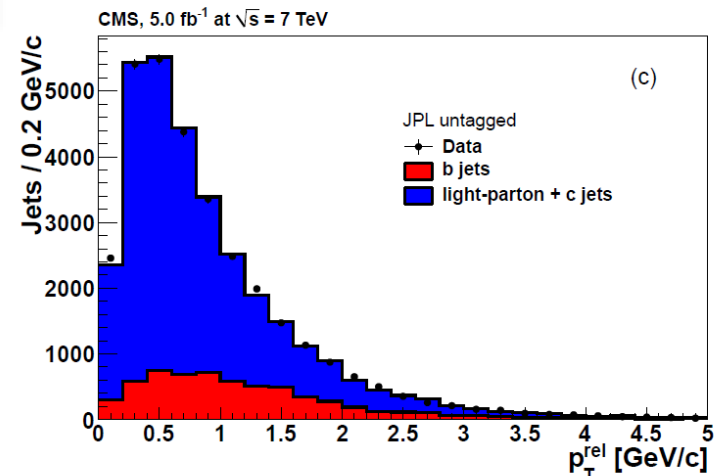
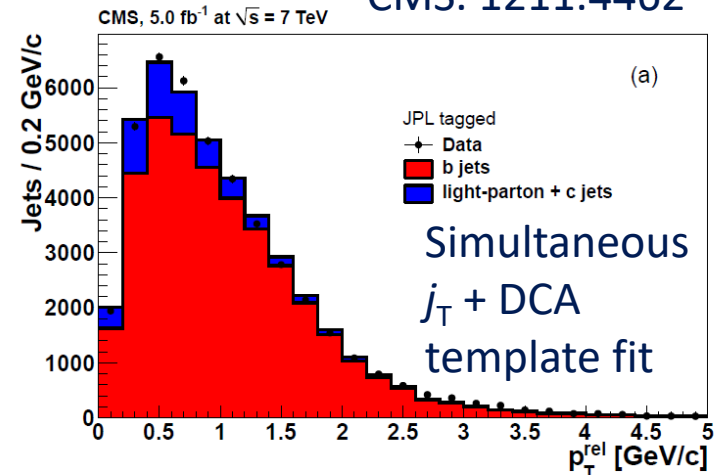
Rejection VS tagging eff.



Suffer of $B \rightarrow \mu$ BR

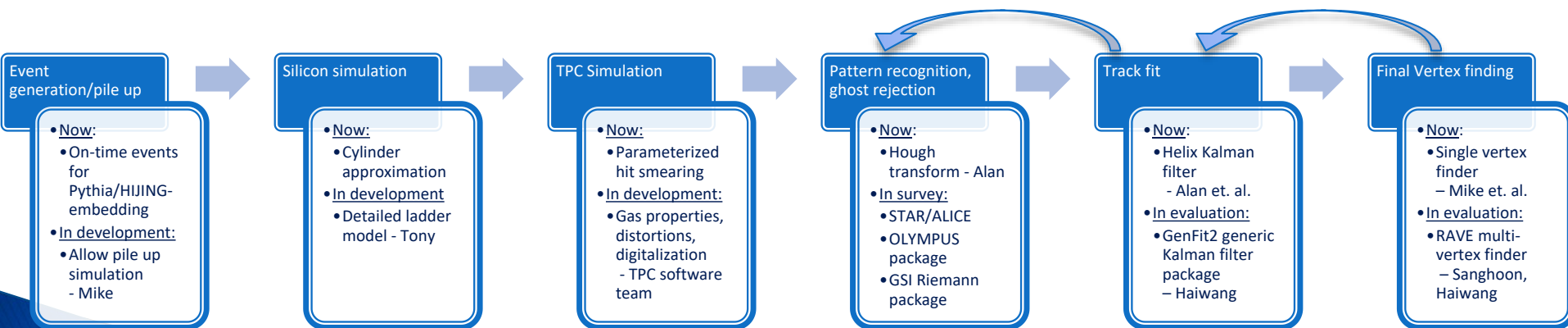
As cross check to JP/L method

CMS. 1211.4462



sPHENIX tracking simulation and reconstruction chain

- ▶ A chain of full detector Geant4 simulation and reconstruction software developed for sPHENIX, used in current detector and physics performance projection
- ▶ Limitations in current software that need to be evolved for the next stage
- ▶ Many new developments hold back before the Sept-tracking review. Now to be coordinated to be made default.



<https://indico.bnl.gov/conferenceDisplay.py?confId=1930>